Nutrient and Sediment Reductions from Algal Flow-way Technologies

Recommendations to the Chesapeake Bay Program's Water Quality Goal Implementation Team from the Algal Flow-way Technologies BMP Expert Panel

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Port of Baltimore Algal Flow-way Installation (Courtesy of the Port of Baltimore)

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List of acronyms

AFT	Algal flow-way technology
ATS®	Algal Turf Scrubber
BMP	Best management practice
CBP	Chesapeake Bay Program
EOS	Edge-of-stream
EPA	U.S. Environmental Protection Agency
O&M	Operation and maintenance
TN	Total nitrogen
TP	Total phosphorus
WQGIT	Water Quality Goal Implementation Team
WTWG	Watershed Technical Workgroup

Section 1. Summary of Recommendations

After reviewing the available science related to algal flow-way technologies (AFTs), the Panel concluded that these practices remove nutrients and sediment that could be modeled as reductions to estimated polluted runoff in the Chesapeake Bay Program Partnership's Watershed Model. Only operators that transport the nutrients and sediment offsite for end use or disposal, or apply the nutrients according to a nutrient management plan are eligible for this credit.

Nutrient Reductions

The Panel agreed that jurisdictions could qualify for nutrient reductions in one of two ways. For planning scenarios and for those operations or jurisdictions that do not have access to regularly sampled algal production weights and nutrient concentration analyses of algae produced, a jurisdiction may claim a reduction of 545 pounds of total nitrogen (TN) and 45 pounds of total phosphorus (TP) per acre of AFT surface area in operation each year. These "default" reductions are based upon conservative algal production and nutrient concentration estimates of systems in operation around the Chesapeake Bay Watershed. According to the studies provided in Table 2, the Panel found one could conservatively estimate that one acre of AFT surface area would produce approximately 24,787 pounds of algae (dry weight basis) in a single year. The Panel also found that approximately 2.2% of the algae would be made up of TN and approximately 0.18% would be TP. A detailed description of these estimates can be found in Section 4.

Alternatively, jurisdictions have the option to submit results from nutrient concentration analyses of biomass produced by an AFT project along with the dry algal weight of biomass produced. This would result in a more accurate accounting of nutrients removed by these systems. A more detailed description of the submittal procedures and credit calculations can be found in Section 5. These procedures are considered sufficiently general enough to apply to multiple variants of the AFTs.

Sediment Reductions

Similar to nutrients, the Panel agreed that jurisdictions could qualify for sediment reductions in one of two ways. For planning scenarios and for those operations or jurisdictions without access to regularly sampled algal production weights and sediment analyses, a jurisdiction may claim 3,219 pounds of sediment reduction per acre of surface area in operation each year. This value is based upon a conservative estimate of non-biogenic ash content found within studies from across the watershed. A detailed description of this estimate can be found in Section 4.

Alternatively, jurisdictions have the option to submit results of biogenic inorganic dry weight ash concentration analyses of biomass produced by an AFT project. A more detailed description of the submittal procedures and credit calculations can be found in Section 5.

Section 2. Expert Panel Charge

The Chesapeake Stormwater Network hosted a workshop on July, 2012 to discuss the potential nutrient reductions from emerging stormwater technologies including algal AFTs. Workshop participants recommended the Chesapeake Bay Program's Water Quality Goal Implementation Team (WQGIT) form a cross-sector Panel of experts to further explore the potential nutrient reduction benefits of algal flow-ways. Due to the cross-sector nature of the technology, the WQGIT requested that the Bay Program's Watershed Technical Workgroup (WTWG) lead the Panel. The WTWG and WQGIT formed the following charge for the expert Panel. The members of the Panel are listed in Table 1.

Table 1. Members of the Algal Flow-way technologies BMP expert Panel

Last Name	First Name	Affiliation
Bott	Charles	Hampton Roads Sanitation District
Brush	Mark	Virginia Institute of Marine Science
Canuel	Elizabeth	Virginia Institute of Marine Science
Johnston	Matt	University of Maryland CBPO (co-facilitator)
Kangas	Pat	University of Maryland
Lane	Sarah	University of Maryland Center for Environmental Science MD DNR Office (co-facilitator)
May	Peter	Biohabitats
Mulbry	Walter	USDA-ARS
Mulholland	Margaret	Old Dominion University
Sample	Dave	Virginia Tech
Sellner	Kevin	Chesapeake Research Consortium
Stephenson	Kurt	Virginia Tech

Special thanks to: Emmett Duffy, Virginia Institute of Marine Science, Walter Adey, Smithsonian Institution, Alana Hartman, WV Department of Environmental Protection, Mark Zivojnovich, Hydromentia, Inc., Jeremy Hanson, Chesapeake Research Consortium and David Wood, Chesapeake Research Consortium.

The Panelists were asked to complete the following tasks:

- Review the current literature regarding AFTs;
- Review current protocols for quantifying nutrient and sediment reductions used by research scientists and private industry representatives;
- Review monitoring data collected at a variety of sites, both by research scientists and private industry representatives;
- Develop a general description of AFTs to be used as the definition of the practice;
- Provide guidelines for modeling AFTs and other biomass harvesting techniques;
- Develop protocols describing state reporting procedures for removal rates from each project. The Panel should consider protocols for both permitted and non-permitted facilities;
- Ensure that reported removal rates from individual sites are consistent with research or literature reported ranges for other AFTs;
- Consider the proper disposal and/or use of the spent waste byproduct to ensure reductions are occurring; and
- Draft and edit a report describing the Panel's findings and recommendations.

In addition to the core Panelists, a number of contributors were invited to provide input from time-to-time. These contributors were technical experts from the industry and the research community. They assisted with the following tasks to aid the Panel:

- Provide data on estimated removal rates and describe the monitoring protocols for specific sites.
- Provide feedback on a variety of issues when solicited by the core Panelists.
- Review the findings of the core Panelists as they are developed and at the end of the process. It is important to note that the core Panelists and ultimately the Chesapeake Bay Program's Water Quality Goal Implementation Team will approve the final expert Panel recommendations.

The Panel's review followed the process described in the *Protocol for the Development, Review, and approval of Loading and Effectiveness Estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed Model* (WQGIT, 2010). This protocol requires the Panel to review existing literature and data related to the nutrient reduction benefits of the BMP, and make initial recommendations on if and how the BMP should be quantified, reported, tracked and modeled by the Bay Program. These initial recommendations are forwarded to the appropriate source sector workgroups (Agriculture Workgroup and Urban Stormwater Workgroup) and the WTWG for review and approval. After this initial review phase the Panel's recommendations are sent forward to the WQGIT for final approval and subsequent incorporation into the Chesapeake Bay Program Partnership's modeling tools.

Section 3. Description of Practice and Model Definitions

Description of Practice

AFTs have been actively employed in nutrient removal from flowing ambient waters for over three decades (Adey et al. 1993, Adey and Loveland 2007, Adey et al. 2011), with several-acre field deployments in Florida and Texas and smaller scale capacity projects in marine aquaria at the Smithsonian Institution and other research sites. Early experimental work on AFT design and performance ranged across a variety of water treatment applications including agricultural drainage waters (Kangas and Mulbry 2014), industrial pollutants (Adey et al. 1996), heated discharge water from a nuclear power facility (Kangas 2011) and domestic sewage (Craggs et al. 1996a, 1996b, Craggs 2001). A multiyear project was undertaken on treatment of dairy manure which included studies of nutrient removal (Mulbry and Wilkie 2001, Wilkie and Mulbry 2002, Pizarro et al. 2002, Kebede-Westhead et al. 2003, 2004) and end use of harvested algae as a fertilizer (Mulbry et al. 2005, 2006) along with economic assessment (Pizarro et al. 2006). There have been several pilot studies throughout the Chesapeake Bay watershed, in both estuarine and freshwaters (Mulbry et al. 2010, Adey et al. 2013, Ray et al. 2014, Ray 2014), as well as a wastewater treatment plant in Rockaway, Queens, New York City (P. May, personal communication), and field work in Arkansas treating eutrophic waters (Sandefur et al. 2011, 2014).

Per the BMP protocols, the expert panel evaluated peer-reviewed literature and data, and after reviewing these projects categorized the data based on its applicability to conditions within the Chesapeake Bay watershed (length of the growing season, average temperature) and the suitability of the input water to treatment by algae (light penetration, availability of constant flow volume, minimum flow rates). Based on this analysis the use of AFTs for industrial pollutants, heated discharge water from a nuclear power facility, treatment of dairy manure and wastewater treatment do not receive credit under the AFT criteria and reduction rates provided in this report. The use of AFTs at permitted wastewater facilities are allowed, but would be credit and reported under the facilities existing point source discharge permit and associated point source Bay Program protocols. However, these projects provided insight into developing guidelines for harvesting, storing, disposing or using algae. There were four AFT field studies (Kangas et al. 2009; May et al. 2013; Canuel and Duffy 2011; Adey et al. 2013) from the Chesapeake Bay watershed that were used to develop the qualifying criteria, definition and default reduction credit (growing season, flow rate, productivity rates and percent nitrogen, phosphorus and sediment content).

AFTs are inclined (typically 1 to 2˚) systems designed to improve water quality using natural algal assemblages that accumulate on screens or other substrate. In typical AFTs analyzed by this Panel, nutrient-laden water is conveyed from a nearby ambient water source or facility into the upslope end of the raceway and allowed to flow across the screens to a down-gradient outlet. Over time, algae from the ambient waters naturally colonize the screens and assimilate nutrients from the overlying water into algal biomass. This algal growth is strongly dependent upon temperature and light. The algae are regularly harvested and the accumulated algal biomass can be used for biofuels, compost, omega-3 oils, fertilizer, soil amendments, or animal feed. The nitrogen, phosphorus, and sediment in the accumulated biomass is thus removed from the ambient source waters and prevented from entering adjacent waterways. In addition to the nutrient and sediment reductions, these systems also add dissolved oxygen to the water column, an important parameter for Chesapeake TMDL compliance, and most importantly, a critical benefit to increasing habitat for aquatic species.

Figure 1. Example of Algae Filaments Growing on Screen (reprinted from Adey et. al, 1993)

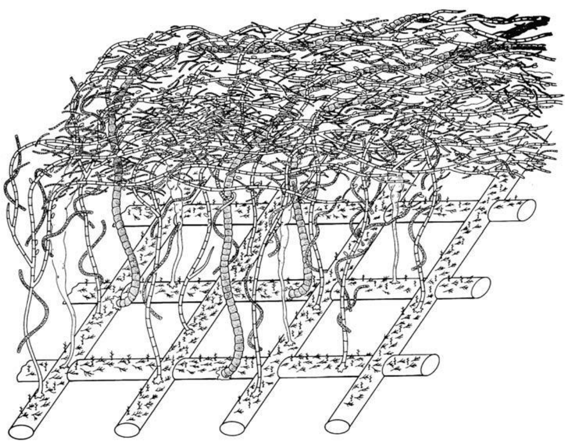


Figure 2. Aerial View of Large-scale Algal Flow-way in Central Florida (courtesy of HydroMentia, Inc.)

The Panel acknowledges that the most common type of AFTs available currently may not be the types of systems that are employed in the future, and that each operation will be designed to take advantage of site conditions and maximize nutrient and sediment removal. For these reasons, the Panel recommended a limited number of qualifying conditions or maintenance and design properties that each AFT must include in order to receive credit within the Chesapeake Bay Program modeling tools. AFTs submitted for credit must have:

1) a continuous flow, subject to normal maintenance and harvesting activities, of nutrient-laden water over an inclined raceway structure to provide water coverage and algal growth OVER THE ENTIRE SURFACE AREA AND THROUGHOUT the production season;*

2) adequate shade-free light for photosynthesis throughout the growing season;

3) a harvesting process for the algae;

4) proper storage of harvested biomass to eliminate runoff of nutrients from the site year-round;

5) an end use for harvested algae (algal nutrients must not be applied onsite unless applications are made under a qualifying nutrient management plan); and

6) an operating system for the duration of the growing season (most commonly 240 days throughout the Chesapeake Bay watershed); if it is less than 240 days, operators cannot claim a default credit and must report more detailed biomass harvest information.

**For a range of typical algal production based on various flow rates, please see Kangas and Mulbry, 2014; Figure B1 in Appendix B.*

The Panel acknowledges that there may be other innovative algae harvesting technologies that also remove nutrients from water, but did not consider any other technologies in their deliberations for this report. Jurisdictions may submit new technologies to the Water Quality GIT for consideration. All proposals for new algae or biomass harvesting technologies will be subject to the *Protocol for the Development Review and Approval of Loading and Effectiveness Estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed Model*.

Model Practice Definitions

The Panel foresees two likely types of AFTs within the Chesapeake Bay Watershed that could receive credit in the Watershed Model:

Non-Tidal Ambient Waters AFT *– Any AFT designed to provide treatment of continuously , ambient, non-tidal surface waters including perennial ponds, lakes, reservoirs, wetlands, streams and rivers.*

Tidal Ambient Waters AFT *– Any AFT designed to provide treatment of continuously flowing, ambient, tidal waters.*

Please note that AFTs used in an NPDES permitted wastewater treatment facility do not receive explicit credit in the Watershed Model as such facilities already report their effluent concentrations and flows to the Chesapeake Bay Program. This should not limit the use of AFTs at such facilities. These concentrations and flows are explicitly modeled, so any impact of an AFT would be captured in these reported effluents.

While the Panel does not recommend different default nutrient and sediment reductions for each of the AFT types listed above, it acknowledges the need to simulate each type differently within the modeling tools. The figures included below illustrate the two ways in which the Panel recommends AFT reductions should be simulated. An AFT for Non-Tidal Waters (shown in Figure 3) would be simulated as a reduction to edge-of-stream loads following the approach used for other upslope BMPs. An AFT for Tidal Waters (shown in Figure 4) would be simulated as a reduction of nutrients and sediment to the loads entering the Chesapeake Bay after all upslope BMPs and in-stream processes have been estimated.

Figure 3. Example Model Simulation of Non-Tidal Ambient Waters AFT

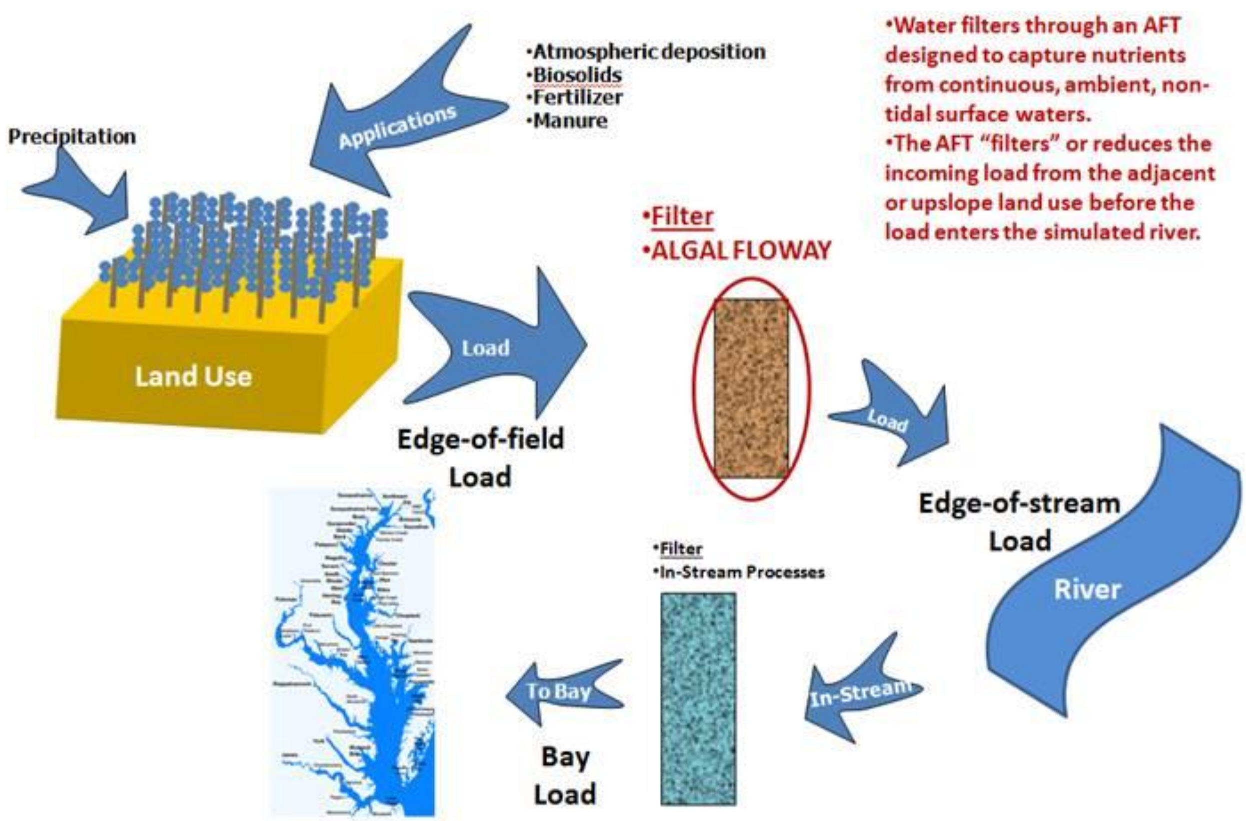
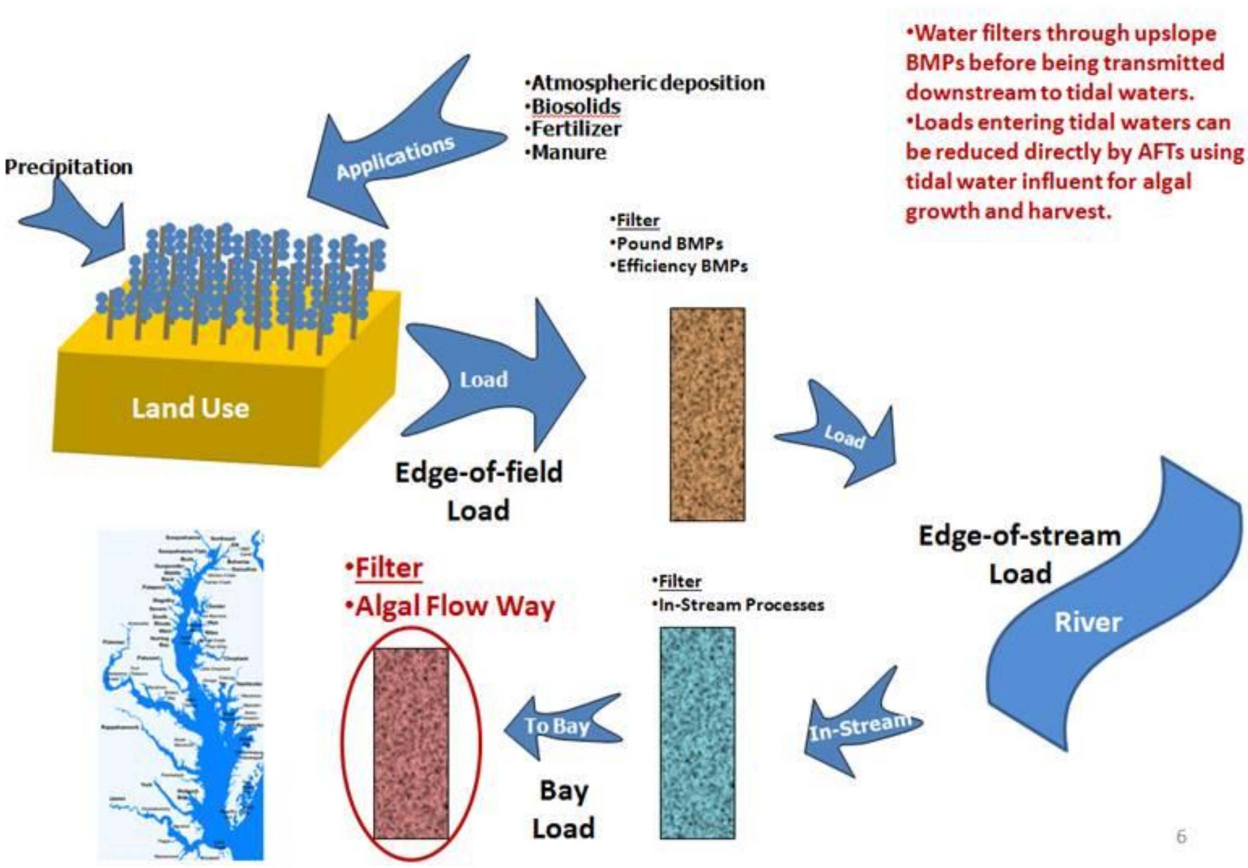


Figure 4. Example Model Simulation of Tidal Ambient Waters AFT



Additional Considerations

The Panel provided information to the Chair, Vice-Chair, Coordinator and Chesapeake Research Consortium (CRC) Career Development Staffer of the Habitat Goal Implementation Team (GIT), and the Chair of the Submerged Aquatic Vegetation Workgroup, to solicit their input on the potential benefits and issues AFT may have on habitat and wildlife. The group discussed the impact of high pH and low CO_2, alterations in temperature, landuse alterations and potential wildlife mortality as a result of the AFT pumping system. The AFT design incorporates screens at the intake site to reduce entrapment of aquatic biota and hence, this issue was quickly eliminated as a potential concern. Reviewing data on the temperature, pH and CO_2 discharges from an AFT shows levels are initially higher than ambient conditions for pH and temperature, and lower for CO_2. However, these three parameters are quickly diluted by the large flow in ambient water and return to levels naturally found in those waters. In the future, large AFT facilities may be constructed in the Chesapeake Bay watershed. It is the recommendation of the Habitat GIT and expert Panel that forested parcels be avoided as sites for AFT facilities to reduce habitat and wildlife impacts. Through the existing permitting process each jurisdiction will also review AFT facilities to minimize their impacts on spawning areas for trout and anadromous fish species. Ultimately, it is the responsibility of each jurisdiction's permitting agency to determine eligible locations for AFT facilities. Overall, the Habitat GIT and expert Panel ultimately agreed that proper siting and design of an AFT should eliminate any unintended adverse consequences to water quality, habitat and wildlife.

Section 4. Pollutant Reductions Based on Literature Studies

Nutrient Reductions

AFTs treat nutrient-rich water using periphyton species. The algal cells assimilate inorganic nutrients, nitrogen and phosphorus, from the water for their growth. AFTs do not require or utilize imported nutrient sources to facilitate algal growth. When algal biomass is harvested, the nutrients associated with the accumulated biomass are removed from ambient waters. While nutrient removal generally increases with algal production and with ambient nutrient concentrations, algae cultivation rates change with slope, screen dimensions, seasons, flow rates and slope length. This can make it difficult to estimate the typical nutrient removal that any one system could achieve.

Nutrient removal for AFTs is typically assessed by simply multiplying the grams of dry weight biomass harvested by the percent nutrient content of that dry weight. Other approaches of quantifying nutrient and sediment removal such as influent/effluent sampling may not accurately reflect the total nutrients and sediments removed by AFTs. The Panel concluded that estimates of mass N and P content in harvested biomass generally provided scientifically sound values for estimating the nutrient removal effectiveness of any system.

The Panel reviewed a number of small-scale AFT studies from across the Chesapeake Bay region that reported the algal nutrient content and biomass productivity. The nutrient content in algae produced in flow-ways ranged between 1.3 and 3.2% for nitrogen and 0.1 to 0.3% for phosphorus (see Table 2). The values from the literature represent the average nutrient content and biomass from the entire system.

Oftentimes nutrient content and biomass can vary across the length of the flow-way due to site conditions (Appendix B, Table B1). Conventional 2-D flow-way designs generally produce less than 20 g DW per meter per day, but emerging evidence suggests that 3D designs could double this productivity (Adey et al, 2013).

Table 2. Comparison of AFT Field Studies from Chesapeake Bay Region

Location	Waterbody Treated	Growing Season (months)	Flow Rate (L/minute/meter)	Productivity (gDW/m2/day)	%N (S.D.)	%P (S.D)
Lancaster, PA(1)	Susquehanna River	8	173	12.9	2.5 (0.52)	0.3 (0.06)
Baltimore, MD(2)	Inner Harbor	12	361	7.7	3.2 (0.60)	0.1 (0.01)
Gloucester, VA(3)	York River	12	100	~20	1.3 (0.45)	0.2 (0.05)
Reedville, VA(4)	Great Wicomico River	12	125	15.4 (2D screen)*	2.5 (0.07)	0.2 (0.05)

(1) Kangas et al. 2009; (2) May et al. 2013; (3) Canuel and Duffy 2011; (4) Adey et al. 2013
*A 3D screen at the Reedville location actually produced between 39.6 and 47.7 g DW/m2/day. This result was not included in the conservative estimate of productivity because of it was the only example of a 3D screen.

Estimates of the total pounds of nutrients removed in a year can be calculated by multiplying a daily biomass production estimate by the number of days of algal production (growing season), and converting the units to pounds per acre per year. The equation below was used to define the average and range of pounds of nutrients removed in a single year per acre of AFT as described in the literature.

Equation 1. Calculating Yearly Nutrients Removed by an AFT
Lbs Removed/Yr = (g DW/m2/day) X (% Nutrient Content of DW Biomass) X (Growing Season Days) X (4,047 m2/acre) X (0.0022 lb/g)

545 lbs TN = (11.6 g DW/m2/day) X (0.022 TN) X (240 Growing Days) X (4,047 m2/acre) X (0.0022 lb/g)

45 lbs TP = (11.6 g DW/m2/day) X (0.0018 TP) X (240 Growing Days) X (4,047 m2/acre) X (0.0022 lb/g)

Using this equation, the estimated nutrients reduced by AFTs at study sites across the Chesapeake Bay region varied greatly. The range of nitrogen removed was 689 lbs/acre/year to 1,251 lbs/acre/year, while the range of phosphorus removed was 25 lbs/acre/year to 130 lbs/acre/year (see Tables 3 and 4). The Panel also reviewed a dairy manure study and agricultural drainage ditch study, but opted not to consider the reductions found in these studies as these particular AFTs would not qualify for credit under the definitions established by the Panel (Mulbry et al. 2008;). Finally, the Panel reviewed a number of studies not listed in Tables 3 and 4, but elected to only analyze those listed as data from these studies reflect large-scale applications in the field that were operated continuously during a single year. The Panel concluded the longevity of these studies appropriately captured fluctuations in production throughout the year.

Table 3. Estimated Nitrogen Reductions from AFTs

Study	Productivity (g DW/m2/day)	g DW N/g DW	Growing Days	m2/acre	lbs/g	Estimated Lbs TN Removed/m2/Year
Lancaster, PA (1)	12.9	0.025	240	4047	0.0022	689
Baltimore, MD (2)	7.7	0.032	365	4047	0.0022	800
Gloucester, VA (3)	20	0.013	365	4047	0.0022	845
Reedville, VA (4)	15.4	0.025	365	4047	0.0022	1,251
Average	14	0.024	240*	4047	0.0022	718
Lowest Quartile	**11.6**	**0.022**	**240***	**4047**	**0.0022**	**545**

(1) Kangas et al. 2009; (2) May et al. 2013; (3) Canuel and Duffy 2011; (4) Adey et al. 2013

*240 growing days defined by the Panel as typical growing season for CB Watershed. The true number of production days will vary across operations, and only operations with 240 growing days would be eligible for the default nutrient reduction credit.

Table 4. Estimated Phosphorus Reductions from AFTs

Study	Productivity (g DW/m2/day)	g DW P/g DW	Growing Days	m2/acre	lbs/g	Estimated Lb Removed/m2
Lancaster, PA (1)	12.9	0.003	240	4047	0.0022	83
Baltimore, MD (2)	7.7	0.001	365	4047	0.0022	25
Gloucester, VA (3)	20	0.002	365	4047	0.0022	130

Reedville, VA (4)	15.4	0.002	365	4047	0.0022	100
Average	14	0.002	240*	4047	0.0022	60
Lowest Quartile	**11.6**	**0.0018**	**240***	**4047**	**0.0022**	**45**
(1) Kangas et al. 2009; (2) May et al. 2013; (3) Canuel and Duffy 2011; (4) Adey et al. 2013						

*240 growing days defined by the Panel as typical growing season for CB Watershed. The true number of production days will vary across operations, and only operations with 240 growing days would be eligible for the default nutrient reduction credit.

The Panel also used the equation to calculate the average annual nutrient reductions likely achieved by an AFT, but recommended that these average reductions be calculated using a growing season of 240 days because algal production typically diminishes or stops during colder months. Because of the variability found in the research studies, to be conservative, the Panel elected to use this lowest quartile for both production (g dry weight/m2-day) and nutrient concentration (g dry weight N or P/g dry weight). The use of conservative recommendations is consistent with requirements described within the *BMP Protocol* (WQGIT, 2010).

Using conservative estimates of nutrient concentrations and production, the Panel estimates that a typical AFT in the Chesapeake Bay Watershed could remove approximately 545 pounds of TN per acre per year and 45 pounds of TP per acre per year. Through the multiplicative application of the lowest quartile for both productivity and nutrient content, the default rate for TN selected by the Panel is actually lower than any production estimate found in the literature listed in Table 3. Again, the Panel reasoned that the use of this conservative estimate was justified because growing conditions can vary substantially from site-to-site.

The Panel acknowledged that these values were based on limited research, and could vary considerably depending upon site conditions and the AFT design and operation. For this reason, the Panel recommends that if possible, operators should sample their algae and report dry weights of nutrients collected (see Section 5 for dry weight procedure) to the Chesapeake Bay Program. Reporting dry weight of biomass (and TP and TN content) integrates nutrient removal over the entire harvest cycle, capturing seasonal variations and differences in production that might occur for any number of reasons. A detailed description of the nutrient reporting needs is provided in Section 5.

Sediment Reductions

The Panel acknowledged that sediment removal rates are difficult to characterize and measure. Depending on conditions (e.g., sediment concentration, grain size and modest flow velocity), sediment is removed from the influent water both by attachment to the filamentous algae or substrate and settling of sediment from the water column to the base of the AFT. However, sediment removal rates vary substantially from project to project. Nonetheless, the Panel attempted to quantify a conservative sediment reduction for a typical AFT operation.

The Panel recommended estimating sediment removal based upon the percent of biomass that is made up of ash and the percent of that ash which is made up of non-biogenic inorganic material. The equation used to estimate sediment removal is included below.

Equation 2. Calculating Yearly Sediment Removed by an AFT

Lbs Sediment Removed = (g DW/m2/day) X (% Ash Content of DW) X (% Non-Biogenic Inorganic Content of Ash) X (Growing Season Days) X (4,047 m2/acre) X (0.0022 lb/g) X (Conservative Reduction)

3,219 lbs = (11.6 g DW/m2/day) X (0.68 Ash Content) X (0.3819 Non-Biogenic Content) X (240 Growing Days) X (4,047 m2/acre) X (0.0022 lb/g) X (0.5)

The Panel found a number of studies that reported the percent ash of the biomass harvested, and these findings are listed in Table 5. Again, the Panel opted to use the 25th percentile of the studies' findings to estimate percent ash content. This resulted in a conservative estimate of 68% ash content. However, the ash contains both biogenic inorganic material (e.g., diatom frustules) and non-biogenic inorganic material. For modeling purposes, it is necessary to credit only removal of the non-biogenic inorganic material from the water column. Only two study sites had estimates of non-biogenic inorganic content, and those are described in Table 6. Non-biogenic ash content from these two sites was lower at the top of the AFT, but increased further down the flow-way as more sediment was collected. The Panel again elected to use the lowest quartile of non-biogenic ash content reported across the entire raceway length in the two studies listed in Table 6. This resulted in an estimate of 38.19% non-biogenic inorganic ash content. Multiplying these two factors yields an estimate of 0.26 g of sediment for every g of biomass harvested. Thus, the Panel found approximately 26% of the material harvested from a typical AFT is likely to be inorganic sediment. Using this approach, the Panel found that 6,437 pounds of sediment per acre could be removed from a typical AFT in a single year.

However, this initial estimate was made using data from short-term duration studies which may not have adequately captured an entire year's sediment accumulation. Due to the limited data and knowledge regarding sediment trapping, the Panel recommended further discounting the sediment removal rate by 50%. This resulted in a final, conservative estimate of 3,219 pounds of sediment reduced per acre per year by a typical AFT. Again, the use of conservative recommendations is consistent with requirements described within the *BMP Protocol* (WQGIT, 2010). The calculation can be found in Equation 2.

Table 5. Comparison of Ash Contents as Percentage of Total Mass from AFTs

Location	% Ash Content	Reference
Oyster Farm, Choptake River, MD	93	Ray, 2014
Peach Bottom, PA	85	D. Blersch, personal communication, 2014
Port of Baltimore, MD	70	W. Mulbry, personal communication, 2015
Gloucester, VA	80	Canuel and Duffy, 2011
Patuxent River, MD	77	Mulbry et al. 2010
Bush River, MD	70	Mulbry et al. 2010
Patapsco River, MD	68	Mulbry et al. 2010
Muddy Run, PA	60	W. Mulbry, personal communication, 2010
Inner Harbor, Baltimore, MD	59	May et al. 2013
Average	75	NA
Lowest Quartile	**68**	NA

Table 6. Biogenic and Non-Biogenic Contributions* to Material Accumulating on AFT after 7 Days (E. Canuel, personal communication, 2014)

Location	Section of Flow-Way	%Biogenic	%Non-Biogenic
Double Flow-Way, Gloucester Point, VA	Top	68.95	31.05
	Middle	58.75	41.25
	Bottom	41.93	58.07
Boat Basin Flow-way, Gloucester Point, VA	Top	62.83	37.17
	Middle	38.86	61.14
	Bottom	35.49	64.51
Average	NA	51.14	48.87
Lowest Quartile	NA	39.63	**38.19**

***** Biogenic and non-biogenic components were separated using Ludox (Varela, 1986; Blanchard et al. 1988). Each fraction was dried at 40°C and weighed. The biogenic and non-biogenic fractions are expressed as a fraction of the total dry weight.

Section 5. Reporting Nutrients and Sediments Removed

Jurisdictions can receive credit for AFTs in one of two ways: 1) using default reductions for nutrient and sediment removal as described in Section 4; or 2) reporting nutrient content and harvested biomass from direct sampling and measurement.

Reporting for Default Credit

For planning scenarios and for operations that do not have the ability to collect samples for harvested nutrients and sediment, jurisdictions should report the type of AFT installed (Non-Tidal or Tidal), the acres of AFTs installed, the location of the AFT and the land use groups (urban or agriculture) that the AFT treats. If reported in this manner, jurisdictions will receive the default nutrient and sediment reductions per acre/per year described in Section 4.

Reporting for Direct Sampling Credit

The second way a jurisdiction can receive credit is by submitting an estimate of annual reductions of nutrients and sediment based upon production weights and direct subsamples of nutrient and sediment content. Because each facility's production results are expected to differ, the Panel strongly recommends this type of reporting when possible. Biomass is typically harvested from AFTs every 7 to 14 days. The Panel recommends that facilities record the weight of dry biomass (step 2 below describes a method to estimate dry biomass) collected during each harvest, and report these results to jurisdictions on an annual basis. Additionally, operators must subsample nutrient and sediment content (Step 3 below) at least four times during the growing season to determine average nutrient and sediment concentrations. A composite of multiple subsamples across the harvested biomass is required to represent average characteristics. Jurisdictions can estimate nutrients and sediments collected using equations 3 and 4. Jurisdictions should then report these annual values to the Chesapeake Bay Program through the National Environmental Information Exchange Network (NEIEN). Estimates of nutrients and sediments removed should be calculated using the following method:

Step 1: Weigh the total biomass collected at each harvest.

Step 2: Weigh a representative subsample of the biomass, and then dry to at least 55°C (131°F) and immediately record the new, dry weight. The difference between these two sample weights is moisture content.

- Perform steps 1 and 2 at each harvest.
- A minimum of four times a growing season, analyze a subsample of the dried biomass for percent TN, percent TP, percent ash solids and percent non-biogenic inorganic content.

Step 3: Use the equations below to estimate TN, TP and sediment removed.

Equation 3. Calculate Annual Removal of Nutrients

Lbs Removed/Year = (g of Total DW Biomass Harvested/yr) X (% Average Nutrient Content of DW subsamples) X (0.0022 lb/g)

Note: Step 2 above describes a method to estimate dry biomass harvested.

Equation 4. Calculate Annual Removal of Sediment

Lbs Sediment Removed/Year = (g of Total DW Biomass Harvested/yr) X (% Average Ash Solids of subsample) X (% Average Non-Biogenic Inorganic Content of subsample) X (0.0022 lb/g)

Note: Step 2 above describes a method to estimate dry biomass harvested. Due to the potentially high cost of sediment analysis, facilities also have the option of reporting TN and TP for direct sampling credit, while electing to receive the default credit for sediment.

Model Credit Duration and Maintenance

The AFT should be considered as an annual practice for crediting purposes. Jurisdictions should resubmit required data to the Chesapeake Bay Program each year regardless of whether the facility is requesting the default credit or the direct sampling credit. Only operations with at least 240 growing or production days may request credit under the default method.

While not related to model credit duration, operators should know that regular maintenance of these systems is typical. While estimates of facility lifespan indicate an AFT can operate for 40 years, plastic liners of raceways often are replaced every 20 years and mechanical equipment every 10 years (Higgins and Kendall, 2012). However, in the saline waters of the Chesapeake Bay, pumps may need to be replaced more frequently than every decade. Also, as part of a facility's maintenance plan, pump screens may need to be replaced annually if they become fouled. This operation and maintenance requires periodic shutdown time for equipment repair, upgrades or replacement.

Section 6. Verification and Accountability

The CBP Partnership is developing a Chesapeake Bay basin-wide BMP verification framework to ensure that practices reported for credit in annual progress reports are installed and functioning in a way that provides the defined water quality benefits credited in the modeling tools. AFTs are still an emerging technology in the Chesapeake Bay watershed and the systems operated within the watershed have thus far been small and operated primarily for academic (research) use and study. Therefore the policies or programs that will govern and regulate the use of these systems are still largely to be determined by the Bay jurisdictions. Given the need for verification and accountability, the Panel provides the guidance below for jurisdictions that will report AFTs for credit under the Chesapeake Bay TMDL. The Panel recognizes that policies or regulations may vary among the jurisdictions, and that the CBP Partnership has yet to approve the full BMP verification framework.

Verification and Accounting for Default Credit

The Panel recommends that jurisdictions consider collecting the following information from AFT operators:

Annual reports that include the type of AFT installed (Non-Tidal or Tidal), the acres of AFTs installed, the location of the AFT and the land use groups (urban or agriculture) that the AFT treats. These annual reports should also include:

- the operator's water appropriation permit number;
- water discharge permit number;
- description of how the harvested biomass was stored;
- description of the end-use of the biomass; and
- operation dates and harvest dates (to ensure 240 operating days)

Jurisdictions may also wish to consider requiring receipts of biomass weight for any biomass leaving the operation. When developing policies or programs to govern and regulate AFT systems jurisdictions may also provide guidelines on proper storage of harvested biomass, and require verification that guidelines were followed.

Verification and Accounting for Direct Sampling Credit

The Panel recommends that jurisdictions consider collecting the following information from AFT operators:

Annual reports that include estimates of the total mass harvested, percent moisture content, percent dry weight nitrogen, percent dry weight phosphorus, percent dry weight ash, and percent dry weight ash inorganic content. The Panel further recommends that these annual reports include:

- the operator's water appropriation permit number;
- water discharge permit number;
- description of how the harvested biomass was stored;
- description of the end-use of the biomass; and
- operation dates and harvest dates (to ensure 240 operating days)

Jurisdictions may also wish to consider requiring receipts of biomass weight for any biomass leaving the operation. When developing policies or programs to govern and regulate AFT systems jurisdictions may also provide guidelines on proper storage of harvested biomass, and require verification that guidelines were followed.

Finally, the Panel recommends that the Partnership revisit its reporting requirements for AFTs if the technology becomes widely adopted around the watershed resulting in significant load reductions (i.e., >1% of total load reductions to the Chesapeake Bay for any given year). The Panel was comfortable with assigning default reductions per acre of AFT installed at this time because there are currently only a limited number of small-scale AFTs in operation. If the technology does become widely adopted, the Panel recommends the Chesapeake Bay Program request detailed reporting information from each operation, leaving the default reductions to be used only for planning purposes. This decision however, will ultimately be left to the Water Quality GIT. If systems become more common, more data will be available for a subsequent panel.

End product use

The ultimate use of harvested biomass from AFTs was an overarching concern of the Panel throughout its deliberations. The processing and end use of the algal biomass is a primary factor in the AFT project's ultimate water quality benefits, and will play a role in the project's commercial viability. If larger scale AFTs will be located in the watershed, then the fate of the harvested biomass is a major concern for both the company/individual that owns the AFT system and the CBP Partnership. When reporting, the Panel recommends jurisdictions document in their quality assurance project plans (QAPP) how the byproduct of reported AFTs will be utilized. Examples of acceptable uses include disposal in a landfill or displacement of nutrients through fertilizer resale and/or applications under a nutrient management plan, animal feed, etc.

Section 7. Future Research Needs and Other Recommendations

These systems require a high amount of energy, and thus substantial capital costs. However, there are opportunities to reduce energy consumption and cost. These opportunities should be further explored by the academic and private sectors. One high cost associated with AFTs are the pumps needed to bring nutrient-rich water to the raceway. Emerging technologies may be able to grow algae without the added cost and maintenance of pumps. One way to accomplish this is to deploy algae growing screens within the waterway itself rather than on land. The process for quantifying and reporting nutrient removal described above is directly applicable to this low-energy *in situ* variant of the AFT. Another significant cost is tied to flow rate: the higher the flow, the greater the cost. Current research has identified a range in flow rate, but more work on flow rate optimization could reduce costs while increasing biomass production. In addition, some researchers have suggested locating AFTs near dams and other areas to take advantage of these regulated, but continuous flows.

The utilization of post-harvest biomass is critical to determining the water quality benefit and the profitability of the entity operating the system. Continued research is needed to develop uses for the harvested biomass so that new markets for the product can be established. Potential customers and partners need to be acquired for its ultimate end use.

In addition to receiving credit for the Chesapeake Bay modeling input deck, the Panel acknowledges that the nutrient and sediment reductions could be used for trading or offset credit generation. In particular, Virginia's Nutrient Trading Act authorizes the use of "algal harvesting" to generate credits (SB77, 2012). It may also be possible to generate carbon trading credits through biomass sequestration of carbon by algae in AFTs; however, the Panel's work focused primarily on nutrient and sediment reductions. The Panel's recommendations for verification and end product use should be considered by any state or federal agency considering approving credit or offsets generated by AFTs.

As larger facilities are constructed across the watershed, to the Partnership should analyze data being submitted to jurisdictions and the Chesapeake Bay Program. The panel fully acknowledges that the findings of this report and the current scientific literature describe mainly small-scale AFTs.

Finally, the Panel acknowledges that little research exists to quantify the amount of sediment removed by AFTs. The Panel recommends future AFT studies focus not just on nutrient reductions, but also on sediment removal. These studies may lead to future changes to the default reductions described in this report.

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Appendix A. Expert Panel Meeting Minutes

Algal Flow Way Technologies BMP Expert Panel
First Meeting/Teleconference
Friday, March 29th, 2013, 10:00AM – 12:00PM

Name	Affiliation	Present?
Charles Bott	Hampton Roads Sanitation District	Yes
Dave Sample	Virginia Tech	No
Elizabeth Canuel	VIMS	Yes
Emmett Duffy	VIMS	No
Feng Chen	UMCES	No
Josh Lowman	Towson (Graduate)	Yes
Kevin Sellner	Chesapeake Research Consortium	Yes
Kurt Stephenson	Virginia Tech	Yes
Mark Brush	VIMS	No
Margaret Mulholland	Old Dominion University	Yes
Pat Kangas	UMD	Yes
Peter May	Biohabitats	Yes
Walter Adey	Smithsonian Institute	Yes
Walter Mulbry	USDA	Yes
Tom Fisher	UMCES (invited)	No
Sarah Lane (Co-Coord.)	MD DNR	Yes
Matt Johnston (Co-Coord.)	UMD, CBPO	Yes
Non-panelists: Jeremy Hanson – CRC, CBPO		

Introduction of Panelists
Matt Johnston (University of Maryland, Chesapeake Bay Program Office) convened the meeting shortly after 10:00AM. Each panelist took a moment to introduce themselves and their background with Algal Turf Scrubbers (ATS).

Overview of Objectives
Matt encouraged the panelists to treat the meetings as open conversations. He reviewed the Panel's charge and items to consider under the CBP's BMP Review Protocol. **Charles Bott** (HRSD) noted ATS systems are engineered, so he suggested considering capital and O&M costs, and engineering specs for operation in the charge.

Introduction to Algal Turf Scrubbers
Pat Kangas (UMD) provided the group with an introduction to ATS technology. For more details, Pat's presentation is available in the March 29th meeting folder of the Panel's Dropbox. Here are some highlights from his presentation and associated discussion:

- **Pat**: Nutrient removal rate equals the biomass production rate multiplied by the nutrient content of biomass. Production rates range from 10-35 grams dry weight/m^2/day and

nutrient contents are 3-5% total nitrogen and 0.3-0.5% phosphorous. He noted ATS can also add Dissolved Oxygen to the water.
  - **Walter Mulbry** (USDA): in terms of nitrogen species in the algae it is TKN, there's little or no nitrate in algae.
  - **Matt** noted that many BMPs are represented by mass reductions in watershed model.
- **Walter M.**: It is very difficult to estimate the nutrients using upstream, downstream measurements rather than collecting nutrient concentrations. Influent versus effluent and collected algae calculations do not match.
- **Pat**: There is less data on sediment removal than for nutrient removal. It is possible to estimate sediment removal: total dry biomass = ash free dry weight + ash weight. Ash = inorganic sediments + elemental content
  - Sediment removal rate = (total biomass production – ash free production)*(% inorganic sediments)
  - During storm events, the ATS systems will remove a lot of sediments. Using the ash weight approach would be a very conservative estimate.
  - **Matt** asked the panelists to keep in mind that the CBP strives to keep conservatism in its estimates.
- **Pat**: Algae will grow all year, though the production slows in the winter as long as the water does not freeze. We really do not know the growing season of these systems. This panel should consider what the growing season is.
- **Pat**: Major issues for ATS include the large footprint and large amount of electricity required to scale up.
- **Kurt Stephenson** (Va. Tech): is there a response function available that links influent concentration to the system productivity?
  - **Pat**: Not done here in the Chesapeake Bay studies, but Dr. Adey has included this in some of his Florida studies.
- **Pat**: Lower and Upper bound estimates of removal based on productivity: 214 to 3900 lbs N/ac/year and 43 to 390 lbs P/ac/year, with median values of 1029 (N) and 108 (P).
  - He noted UMD has a new website on this area if research: Algal Ecotechnology Center: http://www.enst.umd.edu/algae
- **Matt**: Type of systems we'll be looking at. Maybe if we look at productivity, we don't need to narrow it down. Do we want to include any kind of ATS or narrow it down to just raceways?
  - **Pat**: it needs to be a big scale to have an impact.
- **Matt** asked if data from small scale research projects is comparable to big scale.
  - **Walter Adey**: part of the great Wicomico study, compared to corn and soy, the ATS produces several times more biofuel.
  - **Pat**: There is not a commercial scale system in the Chesapeake Bay region.
- **Walter A.**: HydroMentia has been operating a 5-acre system for 3 years and have been contracted for another system since the other project has been so successful. Believe they report biomass and nutrient content.
- **Sarah Lane** (MD Dept. of Natural Resources) noted the panel will eventually need to consider reporting and tracking, so it would be useful to contact Florida and learn more about the experiences with HydroMentia.
  - **Peter May** (Biohabitats) agreed to follow up with HydroMentia on this.

Literature Collection
Sarah provided panelists with a template for collecting and analyzing literature pertaining to ATS and similar technologies. Panelists are encouraged to collect literature and place it on a Dropbox website for all panelists to view.

- **Matt** asked panelists to suggest any other technologies for review and discussion at the next meeting/call.
- **Jeremy** explained there are separate folders for the literature and meeting/administrative items; folders for the individuals meetings will be made in the latter folder. The literature can be organized into sub-folders however the Panel sees fit.

Next Steps
Matt summarized the next steps for the panel:

- **Peter May** will contact Hydromentia and ask them to talk to us about Indian River, Florida and their reporting experiences with the state.
- Some future agenda topics:
  - Discussion of monitoring from Liz Canuel
  - Options in the Watershed Model for crediting these algal technologies
- **Matt** will provide documentation for the Watershed Model and Scenario Builder
  - **Post-meeting note:** Links to both the Scenario Builder and Watershed Model, v5.3 are available at http://www.chesapeakebay.net/about/programs/modeling/53/

Liz Canuel (VIMS) suggested that the panel use "algal flow way technologies" or other alternative language to avoid confusion with patented Algal Turf Scrubbers. There was general agreement from the other panelists.

Adjourned

Algal Flow Way Technologies BMP Expert Panel
Second Teleconference
Thursday, April 25th, 2013, 2:00PM-4:00PM

Name	Affiliation	Present?
Charles Bott	Hampton Roads Sanitation District	No
Dave Sample	Virginia Tech	No
Elizabeth Canuel	VIMS	Yes
Emmett Duffy	VIMS	Yes
Feng Chen	UMCES	No
Josh Lowman	Towson (Graduate)	No
Kevin Sellner	Chesapeake Research Consortium	Yes
Kurt Stephenson	Virginia Tech	Yes
Mark Brush	VIMS	Yes
Margaret Mulholland	Old Dominion University	Yes
Pat Kangas	UMD	Yes
Peter May	Biohabitats	Yes
Walter Mulbry	USDA	No
Tom Fisher	UMCES	Yes
Sarah Lane (Co-Coord.)	MD DNR	Yes
Matt Johnston (Co-Coord.)	UMD, CBPO	Yes
Non-panelists: Jeremy Hanson – CRC, CBPO; Mark Zivojnovich – HydroMentia		

Welcome & Review of 3/29 Minutes

- **Matt Johnston** welcomed the panelists and verified participants. **Jeremy Hanson** reviewed the March 29th conference call minutes, noting the previous action items were satisfied. He pointed out the Scenario Builder and Watershed Model documentation is available online at http://www.chesapeakebay.net/about/programs/modeling/53/

CBP Model and Scenario Builder

- **Tom Fisher**: are there any ground water time lags in the Watershed Model, or when a BMP occurs is there instantaneous credit?
    - **Matt**: Essentially it's the latter. There is a lag on a small time scale. We expect to incorporate lag times in the next version of the Model (Phase 6) in 2017.
    - **Kevin Sellner**: STAC has a lag-time report with recommendations that will be submitted to the Bay Program this year.
- **Matt** reviewed options for crediting BMPs in the model: efficiency, nutrient source reduction, or a watershed load source reduction.
    - He noted that for watershed load source reductions, the reductions occurs in the simulation before the load enters the segment. One of the BMPs modeled this way is stream restoration.
    - **Tom**: what scale are the load source reductions deducted from: a fourth order stream, or larger, e.g. the Potomac?
        - **Matt**: Segmentation starts for streams with a flow of 100 cubic ft/second or greater, which is much smaller than the Potomac. Believe there are about 2,200 stream segments in the Watershed Model.

- **Matt** reviewed some items for the panel to consider and asked for the panelists' thoughts.
    - **Pat Kangas**: Confident in the nutrient removal calculation, but less so in the sediment calculation. The given formula is likely an underestimate of the total sediment capture since it does not account for sediment trapped in the flow-way or system. The given formula only counts sediment trapped in the algae. Some sediment is trapped in the system, under the ATS screen; this occurs in riverine systems, especially when there are storm events.
    - **Mark Zivojnovich** (HydroMentia) suggested the Panel consider water quality and tissue sample data.
        - HydroMentia captures all the biomass and constantly do tissue sampling. The numbers don't match water quality data. Encourage flexibility, whether through measurement of biomass, or based on an acceptable water quality monitoring program. Caution against panel recommending measurement of mass load only. If panel were to specify designs, it could potentially cause problems with proprietary systems and technologies.
        - **Tom** felt that what is harvested would be a better measure of reductions.
            - **Mark**: when you compare the two, there are significant differences between the data. If you are off by a couple percentage points in the tissue sample (e.g., moisture or nutrient content), the nutrient load can be way off mark.
- **Matt** asked for the panelists' thoughts about potentially crediting ATS as a watershed load source reduction. There were no immediate concerns using this approach as opposed to an efficiency.

Hydromentia's Egret Marsh ATS

- **Mark** noted that nutrient removal rates are quite different facility-by-facility, as well as by season.
- **Mark** described the Egret Marsh and other HyrdoMentia facilities.
    - Biomass is typically harvested every 7-14 days.
    - For new concrete system: Production is good through first 90 days, but will know more about the performance in 12-18 months. Concrete adds about 30% to capital costs, but you can get the grade closer to spec.
    - Processing costs are a significant challenge for algal biomass products. Compost, organic fertilizer and potting media, tend to be HydroMentia's favored options. Even in large systems, the amount of biomass produced is very small. This means it is not economically viable for make biofuels or bioplastics. Container mix for nursery is probably the most likely high-revenue byproduct for algal systems.
    - The more estuarine, the higher the productivity even at lower nutrient concentrations?
    - Nutrient removal is generally in 10-35% range or max 40%
- **Matt** asked what data Florida requires the Egret Marsh facility to submit.
    - **Mark**: The initial year at Egret Marsh had 319 funding so they reported weekly monitoring of composite samples. For this particular watershed, they pulled the nutrient requirements from the TMDL. There are ongoing issues between EPA and Florida.

        - The second facility in the county is treating RO reject water and 90% stormwater. Will be continuously monitored just like a WWTP. Each state is much different and there may be latitudes in the information collected and required. There are weaknesses with both the biomass and water quality approaches. Suggests the panel provides opportunity to submit harvested biomass AND water quality data because both would be useful.
        - For HydroMentia's first ATS project in Okeechobee, we started with both monitoring and biomass measuring. Very tight control over the reporting. The sampling did not match up very well with measuring the whole amount of biomass. Usually water quality measurements are higher than biomass.
    - **ACTION: Mark will share summary sampling reports for HydroMentia's facilities with the Panel.**

Next Steps

- **Matt** explained there is a Google spreadsheet with a list of the literature collected so far on the Dropbox. **ACTION: Panelists will sign up for 4-5 articles to read and summarize**.

Adjourned

Algal Flow Way Technologies BMP Expert Panel
Third Teleconference
Monday, May 20th, 2013, 1:00PM-3:00PM

Name	Affiliation	Present?
Charles Bott	Hampton Roads Sanitation District	No
Dave Sample	Virginia Tech	No
Elizabeth Canuel	VIMS	Yes
Emmett Duffy	VIMS	No
Feng Chen	UMCES	No
Josh Lowman	Towson (Graduate)	No
Kevin Sellner	Chesapeake Research Consortium	Yes
Kurt Stephenson	Virginia Tech	Yes
Mark Brush	VIMS	No
Margaret Mulholland	Old Dominion University	Yes
Pat Kangas	UMD	Yes
Peter May	Biohabitats	Yes
Walter Mulbry	USDA	Yes
Tom Fisher	UMCES	No
Sarah Lane (Co-Coord.)	MD DNR	Yes
Matt Johnston (Co-Coord.)	UMD, CBPO	Yes
Non-panelists: Jeremy Hanson – CRC, CBPO		

Welcome & Review of 4/25 Minutes

- **Matt Johnston** welcomed the panelists and verified participants. He reviewed the April 25th conference call minutes, recalling the suggested method to credit an AFT practice in the model at the edge of land river segment.
    - **Lane:** If a system was exclusively for dairy manure, would we be able to attribute the reduction to agriculture?
        - **Johnston**: Correct, we would be able to attribute reductions to specific sectors in a segment.
- Johnston asked panelists for their thoughts on potential reporting methods, specifically dry weight of biomass versus inflow/outflow monitoring.
    - **Pat Kangas**: one problem is the quality of inflow/outflow monitoring. Spot measurements are not adequate to assess BMP effectiveness. The biomass integrates the uptake process over time.
    - **Kevin Sellner**: Why wouldn't we want both credits?
    - **Peter May**: We've been running two flow-ways in New York City. It was tremendous effort and cost to collect and process all the samples. Strongly recommend the biomass approach if the panel only selects one.
    - **Kangas**: It remains to be determined why the monitoring and biomass numbers don't match up. It also depends what is acceptable to EPA.
    - **Johnston**: from a modeling perspective, biomass is so easy to understand and clean.
    - **Kurt Stephenson**: EPA deals with point sources all the time. We should set a level of rigor that is consistent with existing policy, not necessarily rigor that is as

stringent as scientists. Would caution against choosing one over the other if they can both be reliable in certain conditions.
    - **Walter Mulbry**: there's no practical comparison between the two. Biomass is the most conservative way to go.

Algal Flow-ways Monitoring at VIMS

- **Liz Canuel**'s presentation is available on the panel's Dropbox. Highlights from the presentation and discussion are captured here.
    - Studied two floways: Boat Basin flow-way and Twin Floways. Have about 24 months of data for Boat Basin.
    - She explained their methods for monitoring of biomass.
        - Samples dried at 60^{o}C, weighed and combusted. Remaining ash weighed and subtracted from dry mass to obtain ash-free dry mass.
        - Samples were only collected prior to harvest, during peak algal biomass, so they may not represent nutrient removal efficiencies during different phases of the growth cycle.
        - Optimal harvest was approx. every 6 days during summer.
    - **Sellner**: would cyanobacteria be higher in July or August?
        - **Canuel**: The diatoms dominate during all time periods.
            - For nutrient uptake the toxic species don't matter, but it could be an issue if the biomass is used for fertilizer or compost.
        - **Kangas**: we always look at our species and have never seen toxic species in our studies.
    - **Johnston**: if we're trying to define TSS removal, how will we define the rate if a large part of the ash content is silica?
        - **Mulholland**: it will also matter how we harvest the algae.
    - Nutrient removal generally increases with algal production and with ambient nutrient concentration.
    - Estimated nutrient removal [slide 17] based on average daily production of 18 grams/m2/day: 90 g/m2/yr TN and 14-20 g/m2/yr TP.
    - Algal production increased with temperature and dissolved N
- Questions and discussion
    - **Johnston**: we've discussed monitoring/reporting either biomass or water quality. Could we recommend curves for TN and TP removal based on annual production?
        - **Sellner**: It might be more acceptable to have a seasonal curve. Not all systems will run year round.
    - **Kangas**: the growing season is certainly an important consideration. Production rates are so low in winter that it is unlikely to be economically viable for that season.
        - **Canuel**: We included the low (winter) value to demonstrate how low it is. Running the systems nine months out of the year may be a better model.
    - **Mulbry**: the nutrient content of the algae generally goes up if there is a higher concentration in the water quality. For the dairy manure systems there was a direct relationship between the algal production and the nitrogen added.
    - **Johnston**: we will need an equation to define the maximum removal possible.

- **Mulbry**: the ratio of N:P is pretty tight between the water and the algae.
- **Kangas**: the averages are very consistent and seem to reflect water quality.

Literature Reviews

- **Lane** described some of the findings from her reviewed literature and asked some of the questions that were raised during her reading. She combined her summaries into a table format.
  - **Lane**: Do we want to include a discussion of filtering for solids (as pretreatment) or do we leave that up to the operator?
    - **Mulbry** was unfamiliar with that kind of pretreatment. He noted that the dairy manure systems were different from others and are usually recirculating.
    - **Kangas**: it would be helpful to define exactly what kind of system it is. There could be a lot of confusion if we do not lump these systems into specific categories.
- **Johnston** shared text for alternative biomass harvesting technologies. If the panel keeps its focus on floway technologies, it could recommend that the WQGIT consider similar reporting requirements for other biomass harvesting technologies as they arise. A page or a paragraph on this would let this panel focus on its expertise (floways) and set a template for future expert panels on similar, but different, biomass harvesting technologies.
  - **Kangas**: there are many different types of systems with very different designs, e.g. turf scrubbers versus high rate ponds.
  - **Lane**: If there are design parameters that affect removal, then we may want to address them in the report, e.g. seasonality.
- **Lane**: does the panel foresee a situation where a system goes offline for an extended period?
  - **Mulbry**: Would assume they would report zero biomass for that period when the system is offline.
- **Johnston**: would we recommend monthly, weekly, or annual removals to be reported by the jurisdictions for annual progress?
  - **Lane**: Not every data point is sent to the CBP. We can recommend what the facilities monitor and also recommend what gets reported to the CBP.
  - **Kangas**: the technology grows fast and has such a quick time scale. Weekly could be possible.
  - **Johnston**: Only wastewater has a time-step. Other BMPs are assumed to be 100% effective unless there is a significant rainfall.
  - **Lane**: Perhaps states could collect the metadata and weekly reports for verification, but the CBPO would only need the quarterly or annual numbers.

Next Steps

- **ACTION**: Jeremy will distribute Sarah’s template for use by panelists as they review their selected literature.
- **ACTION**: Jeremy will provide copies of other expert panels’ CBP-approved reports.

Adjourned

Algal Flow Way Technologies BMP Expert Panel
FourthTeleconference
Friday, July 12th, 2013, 1:00PM – 4:00PM

Name	**Affiliation**	**Present?**
Charles Bott	Hampton Roads Sanitation District	No
Dave Sample	Virginia Tech	Yes
Elizabeth Canuel	VIMS	No
Feng Chen	UMCES	No
Kevin Sellner	Chesapeake Research Consortium	Yes
Kurt Stephenson	Virginia Tech	Yes
Mark Brush	VIMS	Yes
Margaret Mulholland	Old Dominion University	No
Pat Kangas	UMD	Yes
Peter May	Biohabitats	Yes
Walter Mulbry	USDA	Yes
Tom Fisher	UMCES	No
Sarah Lane (Co-Coord.)	MD DNR	Yes
Matt Johnston (Co-Coord.)	UMD, CBPO	Yes
Non-panelists: Jeremy Hanson – CRC, CBPO		

Welcome & Introduction

- Matt Johnston welcomed the panelists, verified attendance, and reviewed the afternoon's agenda.

Literature Review

- Dave Sample, Pat Kangas, Kurt Stephenson, Walter Mulbry, and Johnston presented summaries of their reviewed literature. The reviews are in the Panel's Dropbox folder titled "Panelists' lit reviews." Below are highlights from the discussion.
  - Pat Kangas asked Matt and Sarah to provide feedback on the lit reviews and what to include in the reviews for the appendix.
    - Johnston suggested including one or two sentences for each artcle describing the reason for considering, or not considering, the article as it relates to algal flow ways.
    - Sarah Lane: Harvesting is an important criterion to highlight, specifically the quantity of biomass harvested (production).
  - Johnston noted that Mark Zjvonovich from HydroMentia provided some reports and data from HydroMentia's facilities. Still have to sift through all the data.
    - Sellner recommended including all data in his analysis, to indicate high or low variability.
- **ACTION**: CBPO staff will create a master reference list and table on Google docs.
- **ACTION**: Panelists are asked to complete their lit reviews by next call (date TBD).

Draft Report Walkthrough

- Stephenson suggested adding a preamble for section 3.

    - **ACTION**: Kurt will draft text to share with panel.
- Johnston: As a partnership report, the document is intended to define the science and recommend measuring and reporting protocols. Leave it to others to define the technical guidance aspects for installation and operations, etc.
    - Sellner: concerned that some people may try to count some systems that are not real flow-ways. We want to include some basic requirements to ensure that credit it given to proper systems.
    - Johnston: We'll avoid getting too detailed for technical requirements. We can use the preamble to address some of these basic design elements and concerns.
- **ACTION**: Panelists to review the draft report and provide comments or suggested revisions ad nauseam.
- **ACTION**: Matt and Sarah will draft some new definitions.
- Johnston noted that recent stormwater expert panels (Retrofits and New State Performance Standards) moved away from bean-counting the stormwater practices to just measuring the volume retained to determine removal.
- Kangas: There isn't much info in literature on sediment removal.
    - Johnston: We would need info about percentage of diatoms, so we don't inflate credit for sediment removal.
- **ACTION**: Walter to draft some text for the section on sediment removal.
- Sellner: We need to determine what CBPO and EPA currently recommends in terms of particulate sampling and analysis methods.
    - **ACTION**: Matt to check with Peter Tango on sampling/analysis requirements.
- Johnston: We'll put the nutrient reduction section on hold until we've reviewed the HydroMentia data.
- Mulbry: The N and P content for algae is fairly consistent, but production can vary widely from week to week due to operational problems.
- Johnston described Quality Assurance Project Plans (QAPPs) that the jurisdictions submit to the CBPO for their grants. In its QAPP a state has to document how they define and collect data that is reported to the Bay Program.
    - Kangas noted that there will also be end-users or receivers of the algae, which could serve as an additional check in the process.
- Johnston: We can revisit this quarterly/annual timestep reporting discussion at a later call.
    - Sellner: In report, we could recommend to states that they develop guidance or policies for these facilities and their reporting requirements.
- Johnston recapped the action items and thanked the panelists for their time on a Friday afternoon.

Adjourned

Algal Flow Way Technologies BMP Expert Panel
Fifth Teleconference
Monday, August 19th, 2013, 1:00PM – 3:00PM

Name	Affiliation	Present?
Charles Bott	Hampton Roads Sanitation District	No
Dave Sample	Virginia Tech	No
Elizabeth Canuel	VIMS	Yes
Feng Chen	UMCES	No
Kevin Sellner	Chesapeake Research Consortium	Yes
Kurt Stephenson	Virginia Tech	Yes
Mark Brush	VIMS	No
Margaret Mulholland	Old Dominion University	No
Pat Kangas	UMD	Yes
Peter May	Biohabitats	No
Walter Mulbry	USDA	Yes
Tom Fisher	UMCES	No
Sarah Lane (Co-Coord.)	MD DNR	Yes
Matt Johnston (Co-Coord.)	UMD, CBPO	Yes
Non-panelists: Jeremy Hanson – CRC, CBPO		

Introduction & Approval of July minutes

- Matt Johnston welcomed the panelists, verified attendance, and reviewed the afternoon's agenda.

Sediment Analysis

- Liz Canuel reviewed some preliminary sediment removal findings from a couple flow-ways that were operated by VIMS. Her slides are available on the panel's Dropbox. Key questions and discussion points are highlighted below.
  - Kangas: Would like to see the mass removal rate, associated with the biomass (e.g. mg/m2-day). That's the number we're really interested in. Would diatom frustules be included in the mineral?
    - Canuel: Very preliminary results. Would like to do some SCM work on bottom of ludox tubes. Would suspect the diatoms would be with low density biogenic material. We've used same method and had good results with benthic microalgae from sediments and we get good recovery of the microalgae in the organic phase. Rate will likely be low.
      - Kangas: Fantastic, because the difficulty is separating those.
    - Kangas: Assume most sediment is moved through these systems during storm events. Was the data obtained during normal flow events?
      - Canuel: Correct, and they were during summer. Could call them baseline summer conditions.
    - Johnston: There is no other data available on inorganic sediment removal in the literature, so we asked Liz to share this information.

        - Kangas: if we knew contribution was from frustules, we could take alternate approach with ash. We don't know the frustules component. If we could compare the ash numbers with the ludox numbers, perhaps we could come up with a sediment estimate or another perspective on this.
        - Mulbry: Taking biomass would perhaps give upper limits. There might be a low rate of sediment removal. With flow, back of envelope estimate would suggest potentially large amounts of sediment may be passing through. A more efficient sediment trap would likely be to the detriment of the algae system. A constant flow, or simulated wave, in these systems is the opposite of how stormwater practices settle and capture sediment.
        - Johnston: We'll need some data to justify any equations or statements the panel makes on sediment removal. He asked Pat, Liz, and Walter to work on the sediment section for the report.
        - Canuel: A large amount of the ash content is the diatom frustules.
        - Kangas: The current equation in the draft, using ash solids, should be called "non-biogenic content." Could we use the average percentage from Liz in the equation?
            - Canuel: it might tell us how much of the ash might be sediment versus diatoms.
            - Matt asked Liz to get an estimate of non-biotic content.
            - Kangas: The sediment percentage may also depend on the river.
            - Canuel noted the ludox method is not widely used in water quality work, typically used to isolate benthic diatoms from sediment. We should be very careful about interpreting these results and extending them to other systems around the watershed.
                - Johnston: We could list acceptable analysis methods for groups that are interested in using this for sediment credit.
        - **ACTION**: Pat, Liz, and Walter to build table of existing ash content from studies, combined with Liz's data.

Draft Preamble section

- Kurt Stephenson reviewed his preamble text with the panel. Johnston directed participants' attention to the draft definitions and modeling approaches for algal flow-way systems. The following captures key comments or recommended changes from the panelists.
    - Ambient surface water treatment algal flow-way systems (AFS)
        - Change to read: "…adjacent to or within…"
    - Stormwater AFS
        - Johnston explained the system works the same way, but for our purposes it is important for us to define it in the Model. For ambient water we are removing the nutrients directly, whereas for stormwater AFS we are making upland reductions. So there would be attenuation over the landscape from the point of the load reduction.
        - There was some general discussion about how to stack or combine the efficiency of a stormwater BMP with an AFS in the model. It was noted

that only some stormwater BMPs, such as wet ponds, might have the continuous water flow needed for an AFS.
    - After some discussion, Johnston summarized it seems there is consensus that we want to treat upland stormwater and ambient stream systems the same way in the model.
  - On-site agricultural waste treatment AFS
    - Mulbry: This can be very complicated. Depending how the farmer utilizes and manages its manure, there may not be anything to gain from the algae system. Cannot always use the algae product as a fertilizer because it does not necessarily have guaranteed nitrogen content, though it can be sold as a soil amendment.
    - Johnston: This brings up an important point about the fate of the algae. We have a nutrient mass balance model. If the group recommends that the algae is composted or landfilled then we can remove from the system.
    - It was suggested to remove the word ambient from the stormwater definition and to clarify differences in the source water.
  - For Kurt's paragraph, change to "could be illustrative to other practices submitted for review and approval by the Chesapeake Bay Program partnership."
- Kangas reviewed his draft text in which he sought to clarify different types of algal cultivation technologies.
  - Stephenson: what's the source of nutrients for photobioreactor systems.
    - Kangas: Typically an artificial source under tightly controlled systems.
    - Stephenson: these systems would probably already be excluded under the criteria outlined in other paragraphs.

Next Steps

- Johnston: Want to build a second draft before next call. Will continue to work offline over next few weeks. Any final thoughts from the panel?
- Sellner: Reuse of harvested algae: where will that be addressed in the report? We need to talk more about that issue. Do not feel it should be credited if it is applied to landscape and does not replace or reduce other nutrient applications.
  - Walter: In some cases it might not reduce nutrients, e.g. if it is added to dairy manure digesters to increase available carbon. It might even increase the nutrient levels of the manure that gets applied.
- Stephenson: how does the model treat sludge from WWTPs?
  - Johnston: Biosolids are applied to crops and reduce the inorganic fertilizer applied. Virginia is the only jurisdiction that has reported data for biosolids in the progress runs.
  - Stephenson: We could draw on how biosolids are handled and make connections to flow-way bioproducts.
- Sellner: we will need to include language to clarify that the process does not end at the biomass harvest.
- Johnston noted that the panel will also have the opportunity to identify research gaps and needs for future research.
- **ACTION**: panelists to provide thoughts on recommendations for future research.
- Johnston summarized:

- We need summary tables from the literature that list average nutrient and sediment concentrations and removal (**ACTION**: Kangas, Canuel, and Mulbry to put together these tables).
- **DECISION**: We agree to consider the following types of practices for credit in the Model:
    - AFS Adjacent to Tidal and Non-Tidal Waters
        - These systems will remove nutrients from the "end-of-pipe" in the Watershed Model. The nutrients will be removed after all upland BMPs are already credited. These systems can be applied to any land uses.
    - Stormwater AFS
        - These systems will act in the exact same way as "Adjacent" systems in the Watershed Model. The nutrients will be removed after all upland BMPs are already credited. These systems will be applied to Urban land uses.
    - Agricultural AFS
        - We did not agree on how to best simulate these systems. They could act in a similar way to "Stormwater AFS," but the end use of the nutrients in these systems is still very much unknown. Walter, is it most often the case that the nutrients from these systems would be captured and reused? If so, then perhaps we should deal with Agricultural AFS in a slightly different way…
- **ACTION**: Matt will work with Kangas, Mulbry, Canuel, Lane and Stephenson to develop the following:
    - Description of Agricultural AFS Systems
    - Description of AFS systems in general
    - Summary table of nutrient and sediment reductions from pertinent literature
    - Descriptions of tracking, reporting and modeling each type of system.

Adjourned

Algal Flow-Way Technology Expert Panel

Sixth Teleconference Call

Meeting Minutes

Thursday, October 23, 2014

Meeting Objective:

Matt Johnston will walk through the draft report and ask for feedback and revisions.

Discussion:

Section 3:

ACTION: Move carbon and trading portion of practice definition (below) to Section 7 on future direction.

- "In addition to receiving credit for the Chesapeake Bay input deck, the panel acknowledges that the nutrient and sediment reductions could be used for trading. If this were to occur, the same reduction calculations, reporting, recording and verification recommendations stand."
- "It may also be possible to generate carbon trading credits through sequestration by algae in AFTs, however, the Panel's work focused primarily on nutrient and sediment reductions"

ACTION: Accept changes to text made via tracked changes during the meeting.

- Matt posed the following question to the panel: If algae is grown in-situ can't use the defaults from the report. Could growers use the measurement option?
    - The panel responded "no".

ACTION: Under definition add the following language:

- "A steady flow of nutrient-laden water *over a flow-way/raceway structure* during the production season (minimum of 50 L per minute per meter of AFT width)"

Section 4.

ACTION: Add the following language:

- "In light of being conservative, the panel is using the lowest quartile for grams of dry weight produced and fraction of nutrients. By the multiplicative nature of using the lowest quartile for both productivity and nutrient content the default rates are actually less than the lowest quartile."

- "This data reflects large scale applications in the field that have been operated for a year; the panel did not include data from facilities that operated exclusively during the growing season and have higher productivity rates, and thus would increase the estimated pounds removed."

ACTION: Pat Kangas will add standard deviations to Table 2 in order to demonstrate small variations in the fraction of nitrogen and phosphorus.

Sediment Section:

ACTION: Remove language that says, "high precipitation will flush out sediment"

ACTION: Keep 50% of sediment values.

Section 5.

- Matt asked the panel "How often report to bay program versus when measure?"
    - Measure production everytime harvest.
    - Record outcomes at every harvest

ACTION: Include the following language:

- "Report annually to Bay Program/state with a record of outcomes at every harvest."

ACTION: Remove language asking for quarterly reporting

- Matt asked the panel what the appropriate nutrient sampling frequency?
    - If the nutrient fraction is consistent within a facility throughout the year… why require a measurement from each harvesting sample?
    - But variability in biomass moisture content is huge!
    - If want to game the system, fraction of N and P is where to do it.
    - Take sample to consistent dry weight.
    - Suspended algae is more water than other kinds of algae.
    - Do step 1 and 2 at each harvest; and require step 3 nutrient and ash content less often
    - Step 3 – at least four times a year

ACTION: Can report for N and P, but use a default for sediment.

Section 5.

ACTION: Remove Scenario Builder and Watershed Model capacity to accept quarterly, weekly reports

Lifespan Section

ACTION: Delete the following language:

- "justification of quarterly reporting requirement"

- Reporting for N, P and S Credit Section
    1) Default
    2) Direct Sampling

ACTION: Improve Formatting

Section 6. Verification and Accountability

1) Default
2) Direct Sampling

ACTION: Change formatting and make additions

- Provide acres,
- If using default, want more than acres and location. Also ask for water appropriation (withdrawals) and water discharge permit numbers/application
- Record use of end use too of both default and direct sampling

ACTION Add as new section: Model Credit Duration and Operational Lifespan

"pump" screens

- First paragraph "annual BMP" not cumulative.

ACTION: Add references to Table 3 and Table 4

- Does the Habitat GIT have to approve the report, or just be given the opportunity to review it?
    - Only review during 30-day open comment period.

ACTION: Complete technical appendix for report.

Adjourned

Algal Flow-Way Technology Expert Panel
Teleconference Call

Meeting Minutes

November 19, 2014

Meeting Objective:

Walk through the draft report and ask for feedback and revisions.

Discussion:

- Defined GIT acronym in charge, define NEIEN in reporting
- Debated the level of specificity to address in the definition
  - Stipulate incline degree as 1-2 ˚?
  - List the kinds of algal assemblage?
  - Define what "steady flow" means in gal/min?

- Debated use of median vs lowest quartile for productivity and nutrient concentration, percent ash content. Ultimately decided on lowest quartile for increased conservation factor.
- Discussed direct sampling credit for:
  - 1) Step 3- define/ rec'd sampling at regular intervals in growing season? Or 4x a growing season?
  - 2) Step 2- clarify drying method?
- Section 7 is the added language (VA trading, in situ screens) appropriate for this kind of report? May appear promotional. Kept language
- Ref's missing, citations inconsistent

Adjourned

Algal Flow-Way Technology Expert Panel

Teleconference Call

Meeting Minutes

December 5, 2014

Meeting Objective:

Walk through the draft report and ask for feedback and revisions.

Discussion:

- Clarify between membership and contributors
- Rewrite description:
  - 1) to included incline? Yes
  - 2) added paragraph on history/background
- Format figure numbers, titles
- Do not define steady flow
- Added forth bullet on storage for credit
  - Require receipt for operators selling or transporting nutrients? If yes, could add to verification section
- Homework= Liz and Pat review standard deviations in Table 2.
  - Pat confirmed results normalized over growing season- thus table ok as is
- Determined only operation with 240 growing days eligible for default credit- added to table 3 and 4
- Homework= personal communication citations need to be confirmed
- Direct sampling- step 3 becomes minimum 4x growing season
- Step 2 language added to define method to estimate dry biomass sample
- Discussed balanced between defining operational procedures and writing BMP report. Language on storage of harvested biomass edited.
- Added language for operation dates and harvest dates

Adjourned

Appendix B. Supporting Literature and Data

Standard deviations of nutrient algal biomass concentrations and water flow rates relationships to productivity and nutrient removal are presented below in support of the Panel's selection of annual estimates of algal nutrient content and biomass productivity.

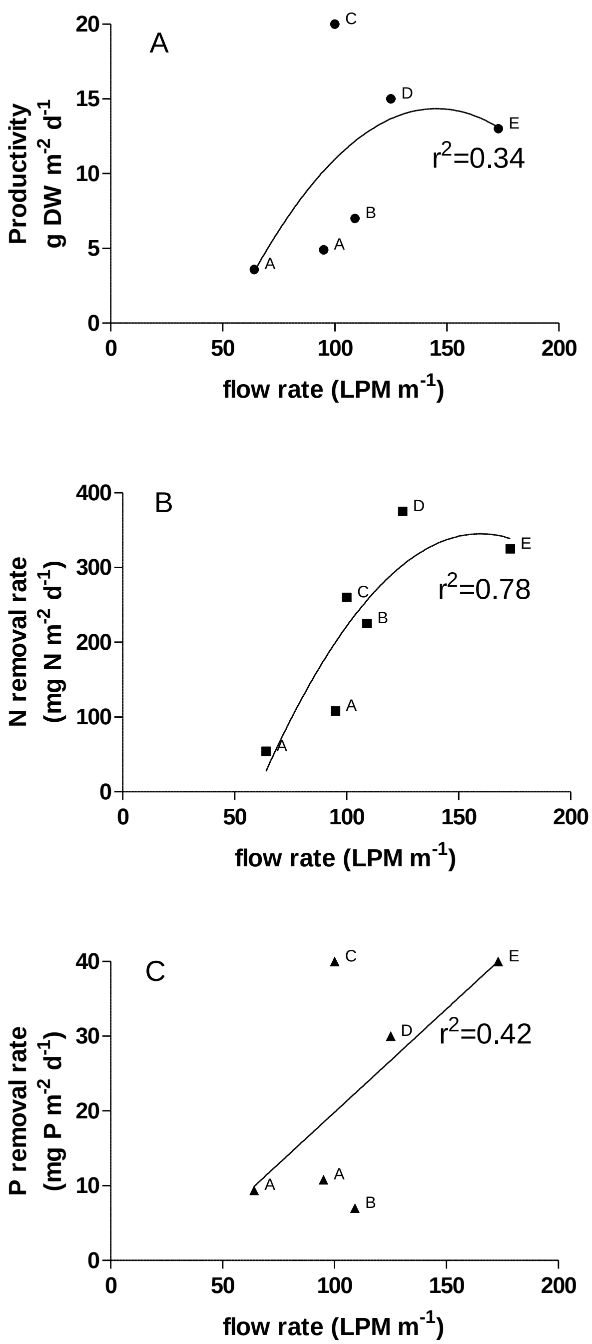
Table B1. Comparison of nutrient contents of algal biomass from experimental floways in the Chesapeake Bay watershed.

Study site	% Nitrogen (± standard deviation)	% Phosphorus (± standard deviation)
Muddy Run, PA (Kangas et al. 2009)		
Aluminum raceway	2.33 (± 0.48)	0.24 (± 0.06)
Wooden raceway	2.59 (± 0.56)	0.25 (± 0.05)
Baltimore Inner Harbor, MD (May et al. 2013)		
	3.20 (± 0.60)	0.05 (± 0.01)
Great Wicomico River, VA (Adey et al. 2013)		
Floway 1 (2 D screens)	2.13 (± 0.07)	0.15 (± 0.05)
Virginia Institute of Marine Science, VA (Canuel and Duffy 2011)		
<u>Boat Basin system:</u>		
Upper floway	1.99 (± 0.74)	0.30 (± 0.17)
Lower floway	1.38 (± 0.50)	0.21 (± 0.09)
<u>Twin Floway system:</u>		
Floway 1, upper portion	1.20 (± 0.41)	0.19 (± 0.09)

Table B1. Continued

Study site	% Nitrogen (± standard deviation)	% Phosphorus (± standard deviation)
Floway 1, bottom portion	1.06 (± 0.34)	0.17 (± 0.06)
Floway 2, upper portion	1.30 (± 0.41)	0.20 (± 0.08)
Floway 2, bottom portion	1.01 (± 0.30)	0.16 (± 0.03)
Caroline County, MD (Kangas and Mulbry 2014)		
Flow regime #1		
(daytime only flow)	1.8 (± 0.3)	0.21 (± 0.05)
(continuous flow)	2.2 (± 0.3)	0.22 (± 0.05)
Flow regime #2	1.5 (± 0.4)	0.26 (± 0.07)

Figure B1. Relationship between ATS water flow rates, algal productivity (panel A) and nutrient removal rates (panels B and C) (from Kangas and Mulbry, 2014).



Values are published and unpublished results from pilot-scale ATS outdoor systems using natural waters in the Chesapeake Bay watershed. Flow rate values are normalized to units of LPM per meter of raceway width (LPM m^{-1}). Symbols indicate study sites: A, Mason Branch, MD (Kangas and Mulbry, 2014); B, Baltimore Harbor (May et al., 2013); C, York River (Canuel and Duffy, 2011); D, Great Wicomico River (Adey et al., 2013); E, Susquehanna River (Kangas et al., 2009).

The figure suggests a non-linear relationship between water flow rates and nitrogen removal rates. Within the low range of flow rates tested (<125 LPM m^{-1}), the N removal rate is linear. Using a raceway of 100 m^2 and a flowrate of 100 LPM m^{-1} of raceway width, this rate corresponds to a removal rate of about 0.14 mg N per liter of water treated. At higher flow rates, the N removal rate levels off and may decline. The relationship between water flow rates and algal productivity or phosphorus removal rates is less clear.

Appendix C. Technical Requirements for the Reporting and Crediting of Algal Flow-way Technologies in Scenario Builder and the Watershed Model

Presented to the WTWG for Review and Approval: November, 2015

Background: In accordance with the *Protocol for the Development, Review, and Approval of Loading and Effectiveness Estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed Model* (WQGIT, 2015) each BMP expert panel must work with CBPO staff and the Watershed Technical Workgroup (WTWG) to develop a technical appendix for each expert panel report. The purpose of this technical appendix is to describe how the Algal Flow-Way Technology Expert Panel's recommendations will be integrated into the Chesapeake Bay Program's modeling tools including NEIEN, Scenario Builder and the Watershed Model.

Q1. How are Algal Flow-Way Technology (AFT) BMPs defined in the Chesapeake Bay Watershed Model?

A1. AFTs are systems designed to improve water quality by using continuous flow of nutrient-laden water over an inclined raceway structure to provide water coverage and algal growth over the entire surface area throughout the entire growing season (at least 240 days per year). The natural algal assemblages that accumulate must be harvested, properly stored in a manner that prevents nutrient runoff, and has an end use such that algal nutrients are not applied onsite unless applications are made under a qualifying nutrient management plan.

Q2. Which land use categories are eligible to receive nutrient and sediment reduction credit from AFT BMPs in the Phase 6.0 Watershed Model?

A2. All urban and agricultural land use categories are eligible to receive nutrient and sediment reduction credit from AFT BMPs. The assumption will be that all non-tidal AFTs treat urban land uses unless otherwise stated by a state. The assumption will be that all tidal AFTs treat tidal water and thus can reduce loads from all land uses adjacent to the tidal water.

Q3. How much nitrogen, phosphorus and sediment reduction credit can a jurisdiction claim for Algal Flow-Way Technologies in the Chesapeake Bay Watershed Model?

A3. The Panel agreed that jurisdictions could qualify for nutrient reductions in one of two ways. For planning scenarios and for those operations or jurisdictions that do not have access to regularly sampled algal production weights and nutrient concentration analyses of algae produced, a jurisdiction may claim a default reduction value based upon conservative algal production and nutrient concentration estimates of systems in operation around the Chesapeake Bay Watershed.

The default nutrient and sediment reduction efficiencies are outlined in Table 1:

Table 1. Default Nutrient and Sediment Reductions Associated with Algal Flow Way Technology BMPs			
Practice	TSS Removal (lbs)	TN Removal (lbs)	TP Removal (lbs)
AFT	3,219	545	45

Alternatively, jurisdictions have the option to submit results from nutrient concentration analyses, or inorganic dry weight ash concentration analysis of biomass produced by an AFT project along with the dry algal weight of biomass produced. This would result in a more accurate accounting of nutrients removed by these systems. A more detailed description of the submittal procedures and credit calculations can be found in Section 5 of the report. These procedures are considered sufficiently general enough to apply to multiple variants of the AFTs. The equations used to calculate the annual nutrient and sediment removals are as follows:

Equation 3. Calculate Annual Removal of Nutrients

Lbs Removed/Year = (g of Total DW Biomass Harvested/yr) X (% Average Nutrient Content of DW subsamples) X (0.0022 lb/g)

Equation 4. Calculate Annual Removal of Sediment

Lbs Sediment Removed/Year = (g of Total DW Biomass Harvested/yr) X (% Average Ash Solids of subsample) X (% Average Non-Biogenic Inorganic Content of subsample) X (0.0022 lb/g)

Q4. What should jurisdictions submit to NEIEN to receive the default credit for qualifying AFTs in the Phase 6 Model?

A4. Jurisdictions should submit the following information to NEIEN to receive the default credits:

- *BMP Name:* AFT (either tidal or non-tidal)
- *Measurement Name:* Total number of acres of AFT installed
- *Geographic Location*: Approved NEIEN geographies: Latitude/Longitude (preferred);County; County (CBWS Only); Hydrologic Unit Code (HUC12, HUC10, HUC8, HUC6, HUC4), State (CBWS Only)
- *Land uses or source category:*
    - Tidal: N/A; this BMP will be simulated adjacent to or within surface waters.
    - Non-Tidal: the default land use group will be UrbanwithCSS, but jurisdictions may report more specific land use groups if appropriate.

If reported in this manner, jurisdictions will receive reductions of 545 lbs TN/acre/year, 45 lbs TP/acre/year, and 3,219 lbs sediment/acre/year.

Q5. What should jurisdictions submit to NEIEN to receive direct sampling credit for qualifying AFTs in the Phase 6 Model?

A5. Jurisdictions should submit the following information to NEIEN to receive direct sampling credit:

- *BMP Name*: AFT (either tidal or non-tidal)
- *Measurement Name*: mass
- *Geographic Location*: Approved NEIEN geographies: Latitude/Longitude (preferred);County; County (CBWS Only); Hydrologic Unit Code (HUC12, HUC10, HUC8, HUC6, HUC4), State (CBWS Only)
- *Land uses or source category:*
    - Tidal: N/A; this BMP will be simulated adjacent to or within surface waters.
    - Non-Tidal: the default land use group will be UrbanwithCSS, but jurisdictions may report more specific land use groups if appropriate.
- *Mass of annual TN, TP, and sediment* collected each year

Procedures and equations used to calculate the annual mass of TN, TP, and sediment collected can be found in Section 5 of the report. Equation 3 should be used to calculate annual nutrient removal, and equation 4 should be used to calculate annual sediment removal.

Q6. What is the credit duration for AFTs in the Model?

A6. The AFT should be considered as an annual practice for crediting purposes. Jurisdictions should resubmit required data to the Chesapeake Bay Program each year regardless of whether the facility is requesting the default credit or the direct sampling credit. Only operations with at least 240 growing or production days may request credit under the default method.

Q7. How should AFTs be verified for proper installation and functionality?

A7. In addition to the information jurisdictions are required to submit to NEIEN, the panel recommends that annual reports also include the following:

- the operator's water appropriation permit number;
- water discharge permit number;
- description of how the harvested biomass was stored;
- description of the end-use of the biomass; and
- operation dates and harvest dates (to ensure 240 operating days for default credit)

Jurisdictions may also wish to consider requiring receipts of biomass weight for any biomass leaving the operation.

Q8. How will the modeling tools estimate the actual load reductions from each Algal Flow Way Installation?

A8. The modeling tools estimate the load reductions differently depending on whether the AFT is tidal or non-tidal. Non-tidal AFTs are treated similarly to stream restoration BMPs in the Phase 5.3.2 Model in that the practices treat runoff that has already filtered through upstream BMPs. The model mimics this upland treatment by simulating non-tidal AFT practices at a watershed outlet. The pounds reduced for each pollutant will be added together and applied as a reduction at the watershed outlet for each model segment. The model simulates further reductions to nutrients between the watershed outlet and the Chesapeake Bay.

Tidal AFTs are treated similarly to shoreline erosion control BMPs in the Phase 5.3.2 Watershed Model. The Watershed Model domain ends at the tidal shoreline, and shoreline erosion loads are actually simulated by the estuarine Water Quality Sediment Transport Model (WQSTM). However, the Watershed Model is the accounting tool used to credit reductions to nutrients and sediments delivered to the Bay by all best management practices. For this reason, the WTWG recommended that reductions from tidal AFTs be counted as reductions in delivered nutrients and sediment from each Watershed Model land-river segment within which the practices are implemented. This will have an identical effect to reducing the nutrient and sediment loads within the WQSTM, but will allow the practices to remain within the accounting and crediting framework.

The WTWG also recommended that the CBP’s Modeling Workgroup consider explicitly simulating nutrient loads from AFTs within the WQSTM for the 2017 mid-point assessment. The WTWG will also discuss if these explicitly simulated nutrient and sediment loads should be reported as loads within the Phase 6 Watershed Model.