West Virginia Department of Environmental Protection

Greenbrier River Restoration Plan

with Adaptive Management Updates

Watershed Assessment Branch, TMDL Section
Revised April 2023

Preface

The Greenbrier River Restoration Plan is an adaptive management strategy for eliminating algae related impairment in the Greenbrier River. The restoration plan was originally finalized by the West Virginia Department of Environmental Protection in October 2013 with implementation beginning in 2014. This 2023 version contains minor revisions to the wording of the original 2013 plan, changing the writing perspective from future to past tense for much of the plan. This updated version also contains information on the implementation and progress achieved by the original plan, as well as adaptive management updates which set new milestones for making further progress toward full elimination of algae related impairment of the Greenbrier River.

In this updated restoration plan, activities associated with the original 2013 plan are referred to as Phase 1. Future activities and milestones make up Phase 2.

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Executive Summary

The West Virginia Department of Environmental Protection (DEP) has included portions of the Greenbrier River on the 303(d) list of impaired waters since 2010, as a result of seasonal algae blooms interfering with the designated uses of the river. Multiple investigations conducted by DEP have determined that significant progress toward restoration of use can be made through the control of phosphorus contributed by point sources discharges.

In 2009 DEP tried to implement NPDES permit requirements to control phosphorus discharges, but the Environmental Quality Board (EQB) identified deficiencies in DEP's permitting strategy and remanded challenged permits to the agency for action. This restoration plan addresses the deficiencies identified by the EQB, incorporates new information, and is based on West Virginia's current narrative water quality standards.

This restoration plan implements a two-phase adaptive management strategy. During Phase 1, final effluent limitations based upon 0.5 mg/l Total Phosphorus discharge were incorporated in the WV/NPDES permits for three publicly owned treatment works (POTWs), Alderson, Ronceverte, and White Sulphur Springs, that DEP has determined cause or substantially contribute to the impairment. Through Consent Orders, the POTWs were afforded time to construct wastewater treatment plant upgrades that enable compliance with the limits. All three facility upgrades became fully operational by 2018, providing tertiary treatment to reduce Total Phosphorus in their discharges. These upgrades have reduced the phosphorous load to the river during critical summer flow conditions by 80-85%, and as a result the production of algae in affected river reaches has reduced by a similar amount. Phase 2 of this plan concentrates on optimizing phosphorous removal at Ronceverte's WWTP and making further improvement to the one area of the Greenbrier River still listed as algae impaired in 2022.

This cooperative approach between DEP and the towns of Alderson, Ronceverte, and White Sulphur Springs has brought about significant progress toward attainment of the designated uses of the Greenbrier River. Implementing this adaptive management strategy as an alternative approach to TMDL development has focused resources where they are needed most and expedited attainment of West Virginia's narrative water quality standards. This strategy is consistent with a United States Environmental Protection Agency (EPA) goal that States may use alternative adaptive management approaches to traditional TMDL development where such approaches are better suited to achieve water quality goals.

Assessment of nutrient contributions from existing sources, measurement of algal growth in the river, and extensive water quality monitoring all support DEP's assertion that reductions in filamentous algae biomass, commensurate with reductions in phosphorous loading from the treatment plants, would occur quickly upon implementation of the point source controls. At the time that the effluent phosphorous limits were implemented, it was DEP's best judgement that these reductions would immediately result in attainment of

West Virginia's narrative water quality standard relative to the growth of filamentous algae in the Greenbrier River – with the caveat that the complexities associated with nutrient loading and algae manifestation preclude certainty. To address this uncertainty, the plan includes multiple year post-construction effluent and instream monitoring to assess attainment progress, as well as provisions to reevaluate causative pollutants/sources and implement additional control actions that may be needed, revising this restoration plan as necessary.

Impairment Description

In 2010 DEP included just over 100 miles of the Greenbrier River on the 303(d) list of impaired streams, recognizing that in any given year 35-50 miles of the river were significantly impacted by filamentous algae and that the areas of impact were all located downstream of sewage treatment plant discharges. By 2013 and at DEP's request, the WV Legislature added language to the Conditions Not Allowable in the Rules Governing West Virginia Water Quality Standards (47CSR2) to prohibit algae blooms which impair or interfere with a stream's designated uses; and DEP better defined its listing procedures for impairments caused by filamentous algae, resulting in the upper section of the Greenbrier above river mile 50.0, and the lower section below river mile 12.1, being delisted in 2014.

Photo 1. Greenbrier River downstream of Ronceverte, near the community of Fort Spring. August 2008.

Photo 2. Greenbrier River downstream of the Hillsboro WWTP discharge. In 2014 this portion of the upper Greenbrier River was determined to not exceed DEP 's new listing threshold for algal coverage and was removed from the 303(d) list. Photo from August 2009.

This restoration plan addresses the portion of the Greenbrier River from mile point 12.1 to mile point 50.0 (i.e., assessment unit ID- WVKNG_02) listed on the EPA-approved 2014 303(d) list as impaired due to non-attainment of its designated uses (public water supply and contact recreation) caused by excessive algal growth, which is prohibited by Section 3.2.g of the Conditions Not Allowable in the Rules Governing West Virginia Water Quality Standards (47CSR2). At that time, algae blooms interfered with the recreational use of the Greenbrier River, typically from late June through the early fall. Also, where public drinking water intakes are located within impacted areas, taste and odor complaints about the drinking water were often associated with the algae blooms. Additional treatment was required to eliminate these taste and odor problems; waters which require this additional treatment are in violation of Section 3.2.h of 47CSR2.

The impaired portions of the river were coded as assessment units WVKNG_02.1 and WVKNG_02.2 on the WVDEP 2016 303(d) list. In 2021, WVDEP completed a project to create relatively static assessment units, and after post-upgrade observations 2018-2022, DEP proposed to delist another 23.5 miles of the Greenbrier for the filamentous algal impairments to contact recreation and drinking water. The only segment retained on the Draft WVDEP 2018/2020/2022 combined 303(d) list was WV-KNG-11 (RM 35.6-49.7), of which only a much smaller section ever exceeded DEP's listing threshold.

Historically, the most severe impacts to the Greenbrier River were from the mouth of Howard Creek downstream to the Talcott area. This section of the river receives the discharges from the White Sulphur Springs, Ronceverte, and Alderson municipal wastewater treatment plants. This plan addresses the primary causative sources in the most impacted section of the river. The plan also includes monitoring a section of the river from Marlinton to Denmar to evaluate the impairment status in that reach in context of DEP's 2013 listing -methodology (attached and discussed in the "Permit Issues" section in this plan).

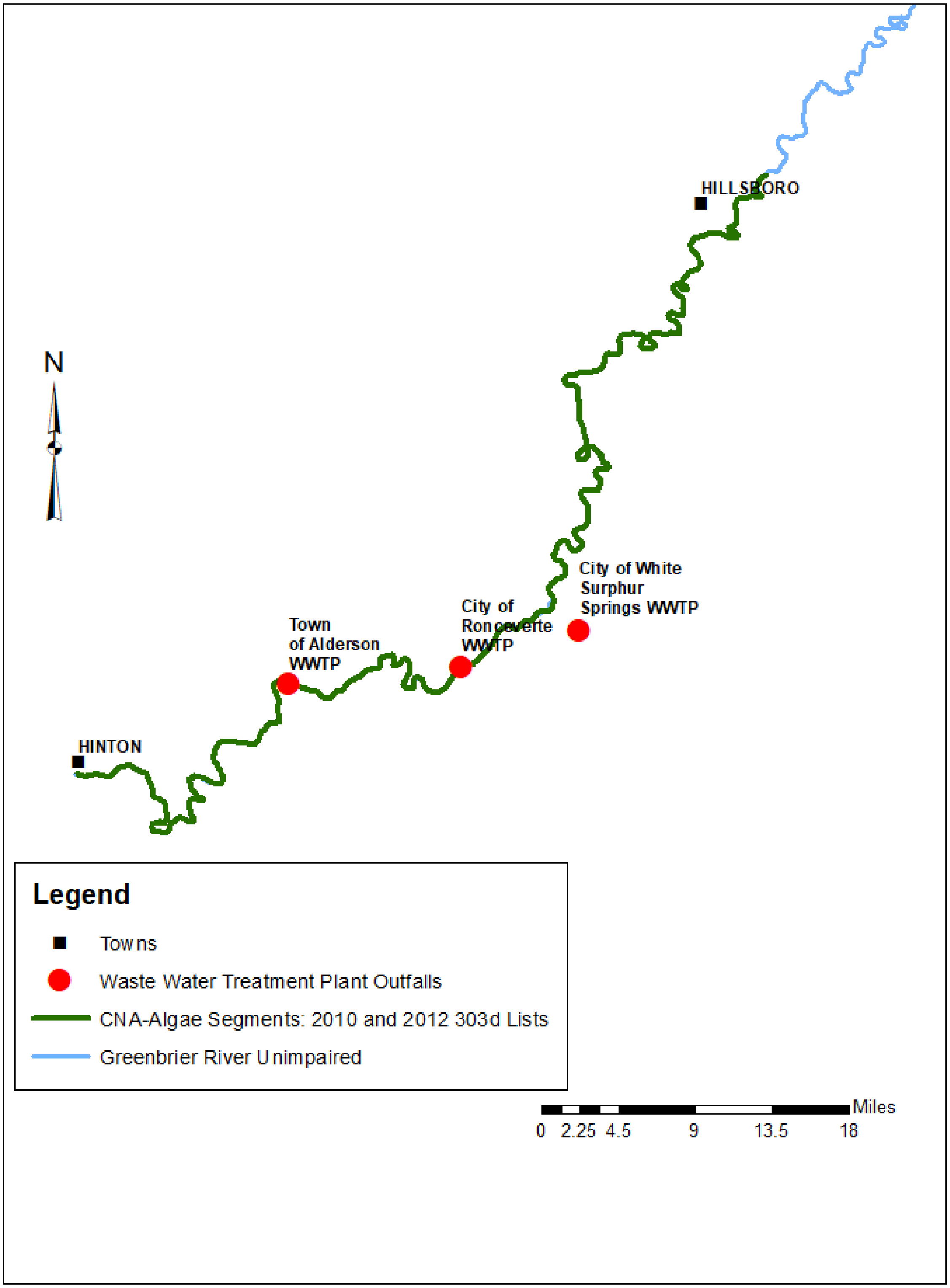

Figure 1. The algae impaired segments of the Greenbrier River in 2010.

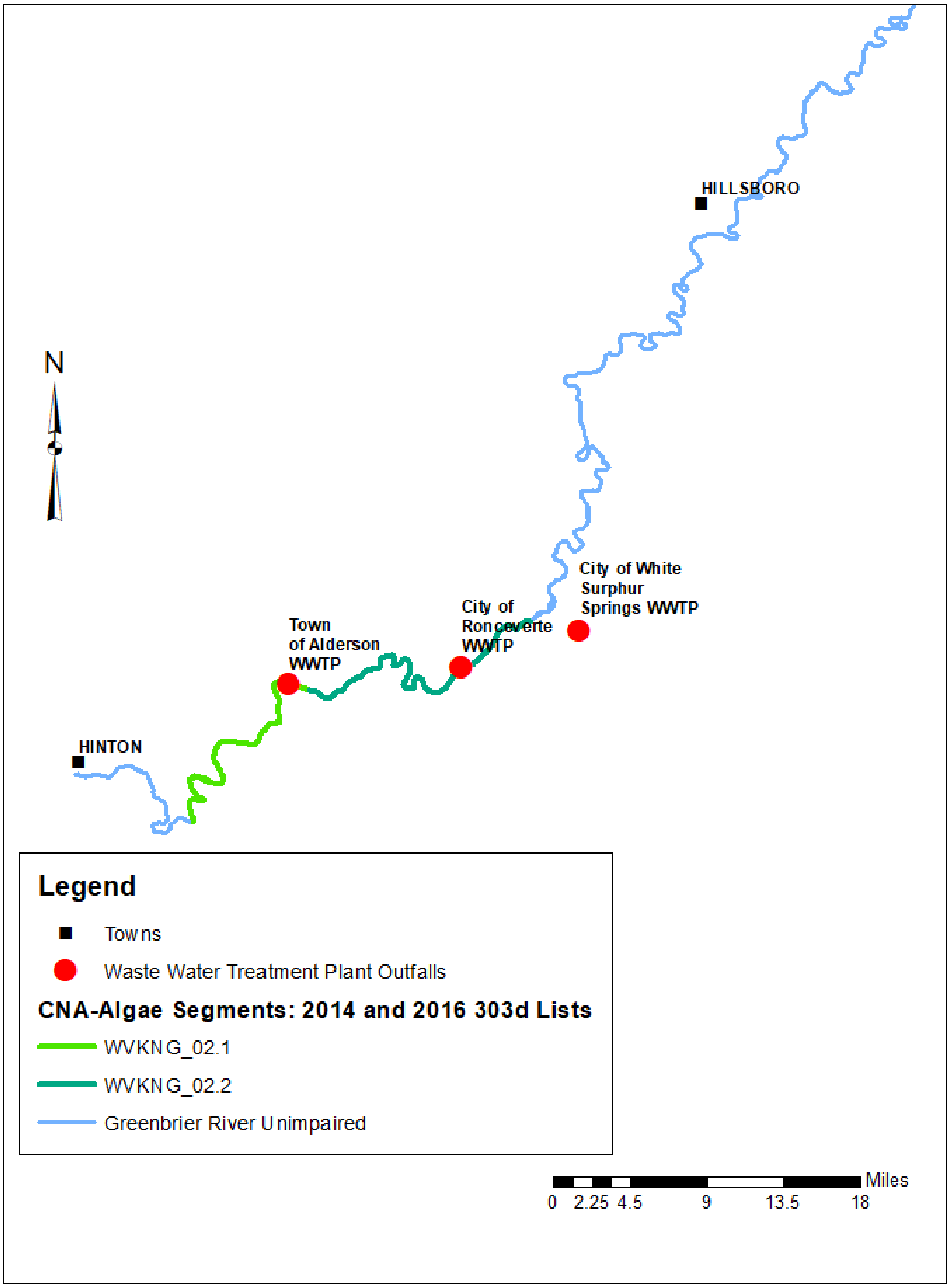

Figure 2. The algae impaired segments of the Greenbrier River in 2014.

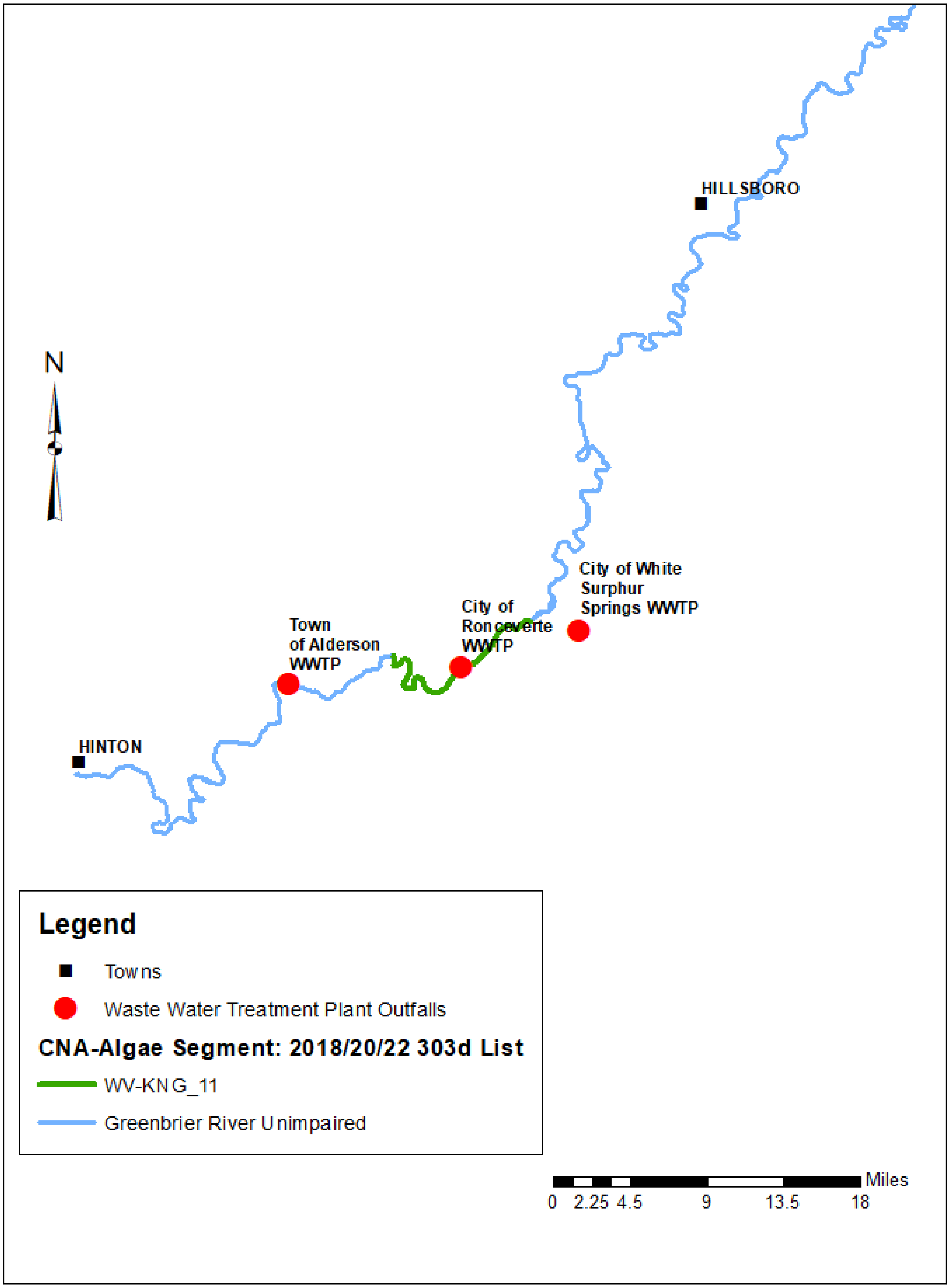

Figure 3. The algae Impaired segments of the Greenbrier River in 2022.

Causative Pollutants and Sources

The December 2008 report from DEP, *Assessment of Filamentous Algae on the Greenbrier River and Other West Virginia Streams* (Attachment D), concluded that "Dissolved phosphorus discharged from sewage treatment facilities along the Greenbrier River is able to combine with nitrates in the river from a variety of sources and cause [these] objectionable algae blooms." In 2010, a subsequent report from DEP, *Nutrient Levels and Filamentous Algae Growth In the Greenbrier River* (Attachment E), summarized an intensive water quality sampling effort on the Greenbrier River. This report concluded that algae growth on the Greenbrier was limited by phosphorus and that controlling phosphorus was the most effective way to reduce the algae growth.

DEP assessments have determined that the point source discharges from White Sulphur Springs, Ronceverte, and Alderson contribute approximately 80% of the phosphorus loading in the impaired section of the Greenbrier River during critical periods[1]. Because the phosphorus contributed by these discharges is largely algal available, DEP expected reduction of phosphorus in these discharges would cause a proportional reduction of algae production. An earlier upgrade of the secondary treatment plant at White Sulphur Springs in 2010 resulted in a moderate phosphorus reduction in the discharge and a proportional reduction of algae growth in the river downstream of this plant. This upgrade did not include treatment units designed specifically for phosphorus removal; rather, the improved effluent resulted in an ancillary reduction of approximately 50% of this plant's phosphorus load. Although the reduction was not enough to completely restore use in this area of the river, the upgrade did provide clear evidence that phosphorus reductions in POTW discharges would reduce the size and duration of algae blooms.

TMDLs and TMDL Alternatives

West Virginia has historically addressed 303(d) impairments by developing watershed TMDLs that include numerical wasteload allocations for point sources and load allocations for nonpoint and background sources. Traditional West Virginia TMDL development includes extensive water quality monitoring and source tracking to allow model representation of all contributing sources in the watershed. The process is expensive, particularly for large watersheds such as that of the Greenbrier River. In addition, developing a nutrient TMDL that includes non-point and background source would be difficult given the complexities related to nutrient availability and filamentous algae growth.

EPA's vision statement *Long-Term Vision for Assessment, Restoration, and Protection under the Clean Water Act Section 303(d) Program* states as a goal EPA's desire for States to "*use alternative approaches, in addition to TMDLs, that incorporate adaptive management and are tailored to specific circumstances where such approaches are better suited to implement priority watershed or water actions that achieve the water quality goals*." EPA encourages the use of the most effective tools to address site-specific water quality protection and restoration efforts.

DEP did not and does not consider traditional TMDL development to be the most effective tool to expedite attainment of West Virginia's narrative water quality standards in this situation. As the types of corrective actions and the magnitude of controls that are needed are generally known, there is little benefit to

[1]. See the "Source Characterization" section of DEP's 2008 report *Assessment of Filamentous Algae in the Greenbrier River and Other West Virginia Streams* for more detailed information on contributions from other sources.

expending resources to quantify all necessary components of an approvable TMDL. Implementation of this restoration plan has resulted in major progress toward restoration – beginning with the WWTP upgrades placed online in 2017-2018 described later in this report.

Conforming with EQB Ruling

Recognizing phosphorus as the limiting factor for algae growth and seeing phosphorus reduction as the most effective way to control algae growth, DEP placed phosphorus limits in the NPDES permits of contributing facilities in 2009. Permits contained short term (interim) phosphorus goals and compliance schedules to install necessary treatment units and achieve compliance with effluent limitations derived from a 0.5 mg/L Total Phosphorus discharge. The permits also contained long term 20-year goals derived from a 0.01 mg/L Total Phosphorus discharge, but it did not compel immediate action toward achieving that level of control. The 0.01 limit/allocation was based on EPA recommended nutrient criteria[2] and would, in theory, absolutely preclude the development of any algae blooms. DEP anticipated the adoption of a new numeric phosphorus criterion that would drive a different final permit limit, well before the 0.01 mg/L effluent limit would have taken effect.

Upon issuance of the permits in 2009, two facilities appealed the permits to the Environmental Quality Board (EQB). In July 2010, the EQB issued a ruling which ordered removal of the permit conditions relating to phosphorus limits and remanded the permits to DEP for action (Section VI, paragraph 8).

The EQB ruling affirmed that "the problems in the Greenbrier River are undeniable" and "clearly at certain times of the year, the river has filamentous algal growth so extreme that certain designated uses have been jeopardized." The EQB never questioned DEP's authority to impose permit limits.

> *The Board finds WVDEP has the authority to correct the problems on the Greenbrier River, but that it must take a more measured approach on how it does it.*
>
> *The end result may be correct, but the process of getting there is the problem. The Board believes that the narrative water quality standards empower WVDEP to take enforcement actions and impose permit limits. However, the process for imposing the limits must be followed and the limits and permit conditions must have clear standards for how compliance is to be evaluated.*

The EQB faulted the process used by DEP to impose the phosphorus limits and the uncertainty of when compliance would be achieved. (DEP contended that it had no intention of ever imposing the final permit limit of 0.01 mg/L Total Phosphorus but was unable to articulate how it could determine when the uses of the river had been fully restored.) The EQB's specific criticisms of the process used by DEP are described below.

The EQB first noted that there had been no formal finding of impairment of the Greenbrier River (i.e., the Greenbrier was not 303(d) listed in 2009.) And during the EQB hearing DEP "did not allege in either its written or verbal testimony that the river is failing to meet its designated uses."

> *Without any finding of formal impairment or any finding of a violation of designated*

[2] EPA recommended the 0.01 mg/L TP criterion for rivers and streams in Nutrient Ecoregion XI. EPA derived this value through statistical analysis (25th percentile) of available water sample results. See "Ambient Water Quality Criterion Recommendations: Rivers and Streams in Nutrient Ecoregion XI" EPA Publication 822-B-00-020, December 2000.

use standards, WVDEP implemented a permit strategy to control algal blooms in the river by controlling phosphorus discharges from the various wastewater treatment facilities that discharge to the river or its tributaries.

The EQB was concerned that DEP had based its action on only two years of data on the Greenbrier River, and that these were relatively dry years. Since algae development is partially dependent on water temperature, river flow, and water clarity, for example, the EQB reasoned that DEP should have a broader base of years to study.

Next, the EQB seemed to fault DEP for imposing phosphorus limits to control algae without allowing for other alternative means of algae control.

Algal growth is the basis of WVDEP's concerns, not phosphorus.

Other alternative means of algal control, including real time water quality management, algaecides, and potential canopy augmentation, are not listed in the Permit.

As a matter of fact and law, there are other means of controlling algal growth to achieve an algal growth standard other than phosphorus removal.

The EQB also stated that DEP "must look at other sources of phosphorus to the Greenbrier River… when seeking solutions to the problem." The EQB was critical that the facilities had "received no Order indicating that their discharges are violating or resulting in a violation of the designated uses of the river or any established water quality standard or criteria."

The EQB ruling emphasized that DEP had imposed permit limits without any scientific finding that either the interim permit limit or the final requirements would "achieve any acceptable standard of algal growth." (Again, this was because DEP could not define what an acceptable level of algae would be.) Further, the EQB held that DEP had implemented these limits and a *de facto* finding of impairment without adequate meaningful input from the public, the legislature, the regulated community, or EPA.

Finally, the EQB was repeatedly critical that DEP had not established any clear standard for the level of in-stream algae that would be acceptable. "WVDEP has failed to develop a workable standard for algal growth." DEP "took no surveys and collected no data with regard to the public's use of the river or its tolerance for algal growth outside anecdotal evidence."

These findings are important, and conforming to the EQB ruling is critical for DEP to move forward in its efforts to restore the use of the Greenbrier River. To that end, DEP has taken several major steps to correct problems pointed out by the EQB in its ruling.

1. The Greenbrier River was formally listed as impaired by excessive algae growth on the 2010 and subsequent 303(d) lists. These listings underwent formal public comment periods, and they were reviewed and approved by EPA.

2. DEP proposed changes to the Rules Governing Water Quality Standards (47CSR2) to clarify that algae blooms interfering with a stream's designated use are not allowable. This change to the rule was passed by the West Virginia Legislature in 2011. (The Legislature did not pass a DEP proposal for a

numeric water quality criterion for phosphorus in the Greenbrier River.) Again, this rule change was subject to extensive legislative review and public comment, and the final rule passed by the West Virginia Legislature was reviewed and approved by EPA.

3. DEP funded a scientific research project regarding the level of filamentous algae that West Virginia stream users found to interfere with their recreational use. DEP has used the findings of this research *(West Virginia Residents' Opinions On And Tolerance Levels Of Algae In West Virginia Waters (*Responsive Management, 2012*))* to develop implementation guidance for the narrative algae standard so that there are clear, scientifically based guidelines for determining impairment. The survey report is available at http://www.dep.wv.gov/WWE/Programs/wqs/Documents/WVAlgaeSurveReport_ResMgmt_WVDEP_2012.pdf and the resulting listing methodology is provided as Attachment A of this document.

4. DEP has continued to measure and study algae development on the Greenbrier and other rivers in West Virginia. DEP has developed a standardized procedure (SOP) for measuring percent bottom cover and percent water column fill (Attachment B). This SOP has been reviewed and used by the Interstate Commission on the Potomac River Basin. DEP has used the SOP to document level of filamentous algae growth and impairment status in the Greenbrier River and other rivers in the state since 2013.

The permittees also took significant steps to correct the algae problem. After the WV Legislature made partial one-time grant funding available to Alderson, Ronceverte, and White Sulphur Springs, these permittees submitted grant applications for funding to upgrade their treatment plants using phosphorus-removal technology. Through the permittees' pursuit and installation of phosphorus-removal technology, the EQB issue regarding alternative algae control methods is minimized.

Other concerns laid out in the EQB ruling are directly addressed in this restoration plan. Specifically, these are:

1. Rationale that a 0.5 mg/L Total Phosphorus effluent limitation will achieve compliance with the narrative water quality standard for algae.
2. Advance notice of this plan and the use of a Consent Order to formally acknowledge that the subject discharges are causing or contributing to a violation of water quality standards.
3. A period of continued monitoring and study of the Greenbrier River for a period of several years to determine if compliance with the narrative water quality standard has been achieved.

The remaining issue from the EQB ruling is that DEP should address other sources of phosphorus in the Greenbrier River basin. While DEP recognizes that there are other sources of nutrients in the river basin, it is clear that the continuous discharge of readily available phosphorus is the primary causative factor in the development of the algae blooms. The critical condition for blooms occurs during periods of low flow. Precipitation induced sources, such as agricultural runoff, are not contributing appreciably to the algal available phosphorus during these low flow conditions. Further, DEP has previously studied runoff from non-point sources of bacteria in the existing fecal coliform TMDL for the Greenbrier River. Implementation of controls and practices to reduce the bacteria loading from agriculture and failing septic systems will reduce the phosphorus loading from these same sources. DEP has also reviewed fertilizer use and management practices at all of the golf courses in the Greenbrier River basin, concluding that no additional management practices are needed. Even though non-point sources are not considered to be significant sources, DEP will continue to periodically review the status of non-point source contributions in the watershed and compile data on progress of non-point source reductions, such as sewer line extensions to assimilate failing on-site systems and improvements made in runoff management from agricultural sites.

Permit Issues

Since the Greenbrier River is currently listed as an impaired water of the state, and because it is clear that POTW discharges of phosphorus contribute significantly to the water quality standard violation, the POTWs are required by the Clean Water Act to implement measures to reduce algae growth in the Greenbrier River.

While the EQB ruling ordered DEP to remove the 2009 NPDES permit conditions relating to phosphorus removal, EPA has stated that it will not approve permits that do not reasonably assure the discharges will not cause or contribute to a violation of water quality standards.

The previous permit strategy included interim effluent limits based upon a 0.5 mg/L Total Phosphorus discharge and 20-year final limits based on a 0.01 mg/L Total Phosphorus discharge, with the assumption that DEP would legislatively pursue a numeric phosphorus water quality criterion and modify the final permit limits when it became effective. When permits were issued in 2009, DEP understood that achieving 0.5 mg/L Total Phosphorus discharges would cause significant reductions in the algae blooms. However, without any standard or guideline of "how much is too much" algae, DEP had to revert to background levels of algae as the acceptable endpoint.

DEP has collected scientific information to determine *West Virginia Residents' Opinions On And Tolerance Levels Of Algae In West Virginia Waters* (Responsive Management, 2012). Using the results from this research, DEP has developed specific guidelines for determining impairment of algae impacted waters in Attachment A (*303(d) Listing Methodology for Algae Blooms* (DEP, 2013)). Rather than background levels of algae as the endpoint, DEP now considers 20% bottom cover for a distance of three times the stream width, never exceeding 40% cover, as the general threshold for impairment. See Attachment A for a more detailed presentation of the criteria for determining when a stream should be listed as impaired. Having a well-defined endpoint that makes allowances for some growth of algae beyond background levels allows DEP to set a final permit limit that is achievable with available treatment technology.

Based upon the West Virginia's narrative water quality standard and the established protocols for assessing impairment, DEP's best judgment when issuing the permits was that compliance with seasonally applicable effluent limitations, based upon a 0.5 mg/l total phosphorus discharge (0.5 mg/l average monthly, 1.0 mg/L maximum daily), would result in attainment of West Virginia's narrative water quality standards in impaired segments downstream of the subject discharges (RM 12.1 to RM 50.0). DEP anticipated this would occur within the growing season following consistent attainment of the permit limits.

Rationale

It has been clearly demonstrated that dissolved phosphorus loading from POTWs along the Greenbrier River is key to the formation of the Greenbrier River algae blooms (DEP, 2009). No impaired areas exist other than those which begin downstream of the POTW discharges.

The 2011 upgrade of the secondary treatment processes at White Sulphur Springs demonstrated that reduction of phosphorus from a POTW discharge will correspondingly reduce the amount of in-stream algae in the Greenbrier River. The average effluent phosphorus concentration of the White Sulphur Springs POTW dropped from over 3 mg/l to 1-2 mg/l after that 2010 upgrade, which did not include treatment units specifically designed for phosphorus removal. This resulted in significant reduction of algae blooms below White Sulphur Springs. While DEP judged this segment of river below White Sulphur Springs to still be impaired, there was significantly less bottom coverage and shorter filaments of algae, as is visible from photographs shown in Photos 3 and 4.

Photo 3 (left). Greenbrier River near Coffman Hill Rd. Approximately 2 miles below Howard Creek. Sept. 2009.

Photo 4 (right). Greenbrier River near Coffman Hill Rd. Approximately 2 miles below Howard Creek. Sept. 2012

It should be noted that the 2009 photo (Photo 3) occurred in a relatively wet year (June-August average daily flow at USGS station at Alderson was 1,008 cubic feet per second [cfs]) compared to the previous two dry years when overall algae impact to the Greenbrier was much higher (431 cfs and 385 cfs average daily flow in June-August 2007 and 2008). The photo from 2012 (Photo 4) was taken at the same location during a drier year (288 cfs average daily flow June-August) but shows significantly less algae growth.

Though there is a reduction of algae biomass corresponding to reduction of phosphorus loadings, it is not known *exactly* by what amount the algae will reduce. The "Redfield ratio" determined a nominal C:N:P (carbon to nitrogen to phosphorus) ratio of 106:16:1 for algae in certain waters, and in phosphorus limited systems, such as Greenbrier, the ratio can be used to confidently predict that reduction of phosphorus will result in reduction of algae. DEP (2008, 2010) determined that as instream phosphorus concentrations approach the background concentration in the Greenbrier River, algae growth diminishes to near background levels (<3% coverage) as well. From a theoretical standpoint, the reduction of algal biomass should be proportional to the percent reduction of algal available phosphorus, i.e., an 80% reduction in algal available phosphorus would yield an 80% reduction in algae biomass. Notably, visual estimates of algal biomass below the influence of the White Sulphur Springs discharge provide support for the theoretical prediction, but true biomass reductions are difficult to accurately quantify in a large river and may vary from year to year in relation to precipitation, temperature, and numerous other factors that can affect the availability of the phosphorus and/or the growth of algae in any given river system at any given time.

Further it cannot be accurately predicted exactly how the reductions in algae biomass will occur over a particular segment of river. Biomass reductions may be manifested through reductions in length of the impaired reach, reduction in the number of days of impairment, reduction of algal coverage of the stream width, shorter filaments of algae, or some combination of these reductions.

However, despite these uncertainties, the Redfield ratio provides the means to predict that in the Greenbrier River, a phosphorus limited system (DEP, 2010), algal biomass should in theory reduce by the same ratio by which the algal available phosphorus load is reduced.

Table 1. Estimated Algal Available Phosphorus (AAP) Reductions in POTW Effluent.

STP	Average Summer Flow (MGD)	Pre-Upgrade Concentration (mg/L)*	Pre-Upgrade Loading (lbs/day)*	Predicted Loading @ 0.5 mg/l effluent TP (lbs/day)	% AAP Reduction (predicted)
White Sulphur Springs	0.971	3.0	23.1	4.0	83
Ronceverte	0.987	3.2	25.3	4.1	84
Alderson	0.261	2.7	5.2	1.1	79
Non-point	-	-	3.2**	3.2	0
Total	-	-	56.8	12.4	78

** Pre-upgrade concentrations and loadings are the averages calculated from the facilities Discharge Monitoring Reports, May through October of 2008-2012 for Alderson and Ronceverte. For WSS the values are based on summer data (May-Oct) from 2008-2010, prior to its initial plant upgrade. Post-upgrade loadings are based on the average flow from each facility for the same reporting period and the 0.5 mg/l effluent Total Phosphorus concentration.*

***Algal Available Phosphorus in the nonpoint source load is estimated at 20% of Total Phosphorus from suspended sediment (Lee, 1980). The non-point source loading shown (3.2 lbs/day) represents 20% of the Greenbrier River's base flow Total Phosphorus load (16 lbs/day) measured upstream of the first major sewage treatment plant discharge.*

As shown in Table 1, phosphorus reductions brought about by the new effluent limits would result in algal available phosphorus load reduction of nearly 80%. While theoretically based, this represents the realistic level of algal reduction (approximately 80%) that DEP expects will be achieved by these upgrades.

If realized, predicted algae reductions would result in blooms that are below the threshold of impairment (see Attachment A - *303(d) Listing Methodology for Algae Blooms*) and would vastly reduce interference with use of the Greenbrier River. Again though, given the uncertainty of how these biomass reductions may be manifested instream, continued monitoring for several years after completion of upgrades will be performed to fully evaluate the progress toward use attainment. Water quality monitoring upstream of the major sewage treatment plant discharges will also give insight into any progress made in non-point source runoff reductions. This substantive reduction of algae is also expected to remove any taste/odor issues associated with the drinking water sourced from the Greenbrier River. DEP will continue to monitor citizen complaints and the treatment plants' need to use additional treatment measures.

Implementation

Implementation of wastewater treatment plant controls for White Sulphur Springs, Ronceverte, and Alderson POTWs was accomplished through the NPDES permitting program and the one-time legislative grant funding. DEP modified the existing NPDES permits after receipt of applications requesting effluent limit revision. The revised permits included monthly average and daily maximum effluent limitations derived from the 0.5 mg/L Total Phosphorus discharge (0.5 mg/L average monthly, 1.0 mg/L maximum daily). Revised effluent limitations are applicable during the months of May through October, inclusively, with weekly self-monitoring and monthly reporting prescribed. Sample permit conditions are displayed in Attachment C. DEP afforded time to construct and make operational necessary treatment facilities through a concurrently executed Consent Order.

DEP will also formally incorporate this plan into its 303(d) and 305(b) reporting activities. Currently, the impairment is contained on the approved West Virginia Section 303(d) list where it will remain until narrative water quality standards are attained. The affected assessment units are classified as Category 5, meaning impaired and in need of TMDL development. EPA's August 13, 2015 memo entitled "Information Concerning 2016 Clean Water Act Sections 303(d), 305(b), and 314 Integrated Reporting and Listing Decisions" provides a framework for states to pursue an alternative restoration approach for impaired waters, such as for the Greenbrier River. Once this restoration plan is accepted by the EPA, the DEP will create a Category 5 subcategory to list the impaired assessment units of the Greenbrier River until which time that the narrative water quality standard is attained or until a TMDL is prepared for the assessment units. A TMDL will not be pursued unless post-implementation monitoring shows the need for additional nutrient reduction from other types of sources.

WWTP Upgrades

DEP originally targeted 2016 as the date for the Alderson, Ronceverte, and White Sulphur Springs municipal wastewater treatment facilities to be upgraded with phosphorous removal technology. Largely due to a catastrophic 2016 flood, which caused massive infrastructure damage in all three municipalities and the surrounding areas, this target was not met. The White Sulphur Springs WWTP and the Alderson WWTP were generally achieving their new permit limit by the end of the summer of 2017. The Ronceverte WWTP did not fully achieve its phosphorous limit until near the end of 2018.

The Ronceverte WWTP had the most extensive upgrade, essentially rebuilding or refurbishing their entire treatment plant. The flow capacity was increased to reduce untreated overflows and enhance treatment processes. Vertical Loop Reactor (VLR) bays were installed to aid in biological phosphorous removal; and equipment for chemical additives and fabric filter discs were installed as tertiary treatment to further phosphorous removal. The Ronceverte facility adds alum and/or poly-aluminum chloride (DelPAC) to the treatment process during May-October when the Total Phosphorus level in the effluent needs to meet the 0.5 mg/L limit.

The White Sulphur Springs WWTP had already added VLRs at their plant during a previous upgrade, so a continuous flushing tertiary sand filter system and associated chemical addition equipment were added to their process to remove phosphorous. White Sulphur Springs currently uses DelPAC as the chemical coagulant to enhance phosphorous removal.

The Alderson WWTP installed a tertiary magnetite ballasting system, including a mixing tank, tertiary clarifier, and chemical addition equipment for phosphorous removal. In 2020 Alderson discontinued addition of magnetite and increased alum feed rates. This, along with continued use of the tertiary clarifier, has improved their effluent phosphorous concentration.

All three facilities are consistently meeting their permit limits for phosphorous, with only occasional excursions.

Monitoring Plan

DEP has regularly monitored instream nutrient concentrations and level of algae growth at strategic locations since 2013 and will continue this monitoring through 2025 (Table 2). Concurrent effluent data is compiled and evaluated to determine progress toward attainment of the narrative water quality standard. To date this monitoring has provided 4-5 years of post-upgrade data, over a variety of stream flow conditions. Data was also gathered from monitoring stations outside of the Alderson-Ronceverte-White Sulphur Springs area. Data from 2013-2018 confirmed that the river was not impaired above mile point 50.0 and water quality monitoring was discontinued from those monitoring locations in 2018. Similarly, water quality monitoring is being discontinued in the newly delisted sections of the Greenbrier River below mile point 35.6 above Alderson after monitoring from 2013-2020.

*Effluent Monitoring***-** Alderson, Ronceverte, and White Sulphur Springs will continue to monitor their wastewater treatment plant effluents weekly for Total Phosphorus and Total Nitrogen from May through October. The concentrations and loadings are reported to DEP monthly on Discharge Monitoring Reports. During Phase 2 of this plan (2022-2025) when Ronceverte's permit is reissued, DEP will consider whether to increase Ronceverte's effluent monitoring from once per week to twice per week during the May-October growing season.

In-Stream Nutrient Levels – During Phase 1 of this plan (2013-2020) DEP monitored monthly May through October at the locations shown in Table 2. In-stream measurements of the temperature, pH, conductivity, and dissolved oxygen were made; and lab analyses performed for Total and Dissolved Phosphorus, Nitrate-Nitrite, TKN, Alkalinity, Total Calcium, Total Magnesium, Total Aluminum, and Total Iron. DEP collects these samples at or near base flow conditions. Sampling for Phase 2 of this plan focuses on the one remaining impaired assessment unit of the Greenbrier River from Howard Creek downstream to Fort Spring. This sampling will be conducted by DEP during the growing season (June – October) through 2025. Phase 1 sampling began in May each year, but flows were often elevated, and no significant growth of filamentous algae was ever documented in May.

The USGS gaging stations on the Greenbrier River at Alderson, Buckeye, and Hilldale will be used to estimate flow at each sample station on an area-weighted basis, relative to the nearest stream gaging station. These flow values will then be used to calculate nutrient loading for each sample taken.

In-Stream Algae Levels – A large part of the monitoring effort will focus on observing and measuring filamentous algae growth at several locations in the Greenbrier River which have had previously documented algae blooms, or previously served as reference sites relative to algae blooms. Measurements of algae development will be made monthly June through October at the monitoring locations, as listed in Table 2.

During Phase 1, longitudinal observations were made at least once per year to document the severity of algae blooms along the length of the river. DEP generally performed these longitudinal assessments to capture information during the period of maximum algae growth. These observations and measurements were used to determine the extent of alga growth and which sections of river were impaired. Sections of the river with greater than 20% algal coverage were documented, as were sections or locations in the river that had greater than 40% coverage. DEP also documented whether these areas were located adjacent to occupied dwellings or public access points. As with stream sampling, Phase 2 longitudinal surveys will focus only on the remaining impaired section of the river. Longitudinal surveys will be done at least annually from Howard Creek to Fort Spring to document the level of algal growth in the river.

Drinking Water Plant Problems - DEP will continue to consult with water suppliers to document odor and taste complaints and document any additional treatment measures taken to control adverse taste and odor.

Table 2. Monitoring Locations*

Location ID	*Location Description*	*Latitude/ Longitude*	*Phase 1 Chemistry*	*Phase 1 Algae*	*Phase 2 Chemistry*	*Phase 2 Algae*
AGB-M00	Greenbrier River above Marlinton WWTP discharge. Left descending bank above Rt. 39 bridge.	38 13 30.6 80 05 42.7	X	X		
AGB-BC1	Greenbrier River below mouth of Beaver Creek.	38 09 27.7 80 08 37.5		X		
AGB-SEE	Greenbrier River at community of Seebert	38 07 57.8 -80 10 34.6		X		
AGB-HB2	Greenbrier River below Hillsboro discharge.	38 06 17.5 80 13 20.1		X		
AGB-D2	Greenbrier River below Denmar Correctional Center WWTP discharge. At old Beard ford.	38 04 26.2 80 13 48.9	X	X		
AGB-64	Greenbrier River above Howard Creek (and White Sulphur Springs WWTP discharge). Under I-64 bridge.	37 47 24.4 80 23 04.0	X	X	X	X
AGB-HC	Howard Creek upstream 0.2 miles from mouth. At Rt. 92 bridge, below White Sulphur Springs WWTP discharge.	37 46 41.9 80 23 40.4	X	X	X	X
AGB-CH	Greenbrier River ~2.5 miles below Howard Creek at Coffman Hill Road Intersection.	37 44 00.4 80 26 09.9	X	X		
AGB-R00	Greenbrier River above Ronceverte WWTP discharge. Above Rt. 219 bridge at city park.	37 44 41.0 80 27 58.6	X	X	X	X
AGB-R2	Greenbrier River in Ronceverte WWTP mixing zone. Left descending bank 0.3 miles downstream of discharge pipe.	37 44 27.2 80 28 42.8		X		
AGB-R3	Greenbrier River at new public access site. Left descending bank 1.3 miles downstream of Ronceverte.	37 43 31.2 80 29 26.0			X	X
AGB-RR	Greenbrier River downstream of Ronceverte WWTP, along Rockland Road. Right descending bank.	37 43 28.2 80 30 41.2	X	X	X	X
AGB-FS	Greenbrier River near Fort Spring. At public stream access point, above spring discharge confluence.	37 45 7.6 80 38 47.8		X	X	X
AGB-GRC	Greenbrier River at Greenbrier River Campground	37 44 25.1 80 34 23.3		X		
AGB-A00	Greenbrier River above Alderson WWTP discharge, near Rt. 3 bridge.	37 43 36.9 80 38 59.4	X	X		
AGB-A2	Greenbrier River below Alderson WWTP discharge	37 42 42.2 80 40 12.8	X	X		
AGB-LBR	Greenbrier River at Lowell Public Access point	37 39 06.1 80 43 46.2		X		
AGB-TAL	Greenbrier River at Talcott Public Access point	37 38 56.6 80 45 04.4	X	X		

* These locations were selected based on current knowledge of existing conditions. The frequency and/or location of these samples may be varied as DEP determines appropriate to quantify conditions in the river.

Post-Implementation Assessment

Phase 1 (2014-2020)

Approximately 12 million dollars in grant funding from the WV Legislature spurred upgrades at the Alderson, Ronceverte, and White Sulphur Springs wastewater treat facilities totaling more than 30 million dollars. DEP had estimated that the new phosphorous removal technology at the WWTPs would lower their combined summertime Total Phosphorous loading by 83%, lowering the river's total "algal-available phosphorous" load by 78%. (See Table 2 in the "Rationale" of this Plan.) Given that the Greenbrier was a strongly phosphorus limited system, DEP predicted a corresponding approximate 80% reduction in algal growth in the river.

Photo 5. Vertical Loop Reactor chamber constructed as part of Ronceverte's WWTP upgrade. August 2018.

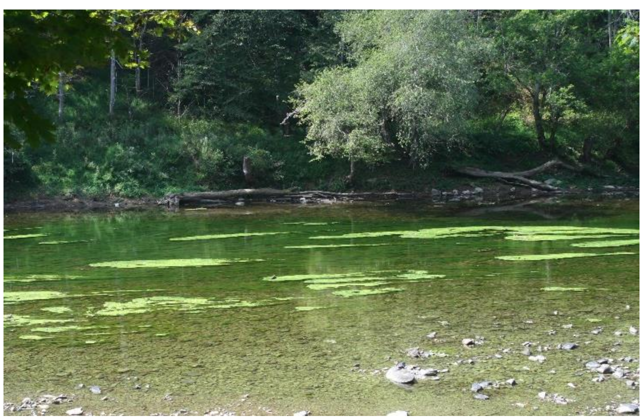

Photo 6. Greenbrier River below Ronceverte at Rockland, prior to WWTP upgrade coming online. September 2016.

Photo 7. Greenbrier River below Ronceverte at Rockland, after WWTP upgrade coming online. August 2018.

Table 3. Reductions to Total Phosphorous with Corresponding Reductions in Growth of Filamentous Algae

Reduction in TP Load (lbs/day) from WWTPs *	Reduction in surface acres of algae (Caldwell to Fort Spring)**	Reduction in stream miles with >40% coverage	Reduction in stream miles with >20% coverage	Reduction in stream miles exceeding impairment threshold	Reduction in stream miles listed as impaired on 303(d) list
79%	84%	94%	93%	89%	63%

** Load reductions compared pre-upgrade years of 2008-2010 to post-upgrade years. The pre-upgrade years were selected to reflect the improvements made by White Sulphur Springs in their 2011 plant upgrade. Post-upgrade dates vary with when individual WWTP upgrades were fully operational.*

*** Given that the growth of algae in the river varies considerably from year to year but generally varies inversely with river flow (all other factors being relatively stable in the river), this reduction was calculated using longitudinal survey data collected in 2014 and 2019 – two comparatively dry, low river flow years having similar flow patterns throughout the summer – with the intent of capturing similar "worst case" conditions, pre- and post-upgrade.*

Table 3 shows that the reductions in Total Phosphorous did result in the predicted substantial, corresponding reductions in algae growth in the Greenbrier River based on observations conducted 2018-2020. Figure 4 illustrates results from longitudinal evaluations comparing the level of algal growth in 2014 to 2019. This illustrates that growth of filamentous algae below White Sulphur Springs was virtually eliminated, except for one persistent area that had 30% coverage for only 50 meters. Below Ronceverte, substantial reductions occurred, but noticeable amounts of algae (10-30% coverage) remained scattered through the section of river from Ronceverte to Fort Spring. However, only one quarter-mile section of the river below Ronceverte exceeded the impairment threshold during the August 2019 longitudinal survey.

A second longitudinal survey in September of 2019, less than 4 weeks after the August survey, showed two different areas with spikes of new algal growth. One of these areas was immediately below the Ronceverte discharge, with a coverage of nearly 70% at a single measurement point extending less than one river width.

Key observations from the 2019 longitudinal surveys are that:

1. Substantial (>80%) reduction in growth of filamentous algae occurred below the WWTPs.
2. Reductions below White Sulphur Springs were more complete compared with the persistent growth below the Ronceverte WWTP discharge that occasionally exceeded the impairment threshold for short distances.

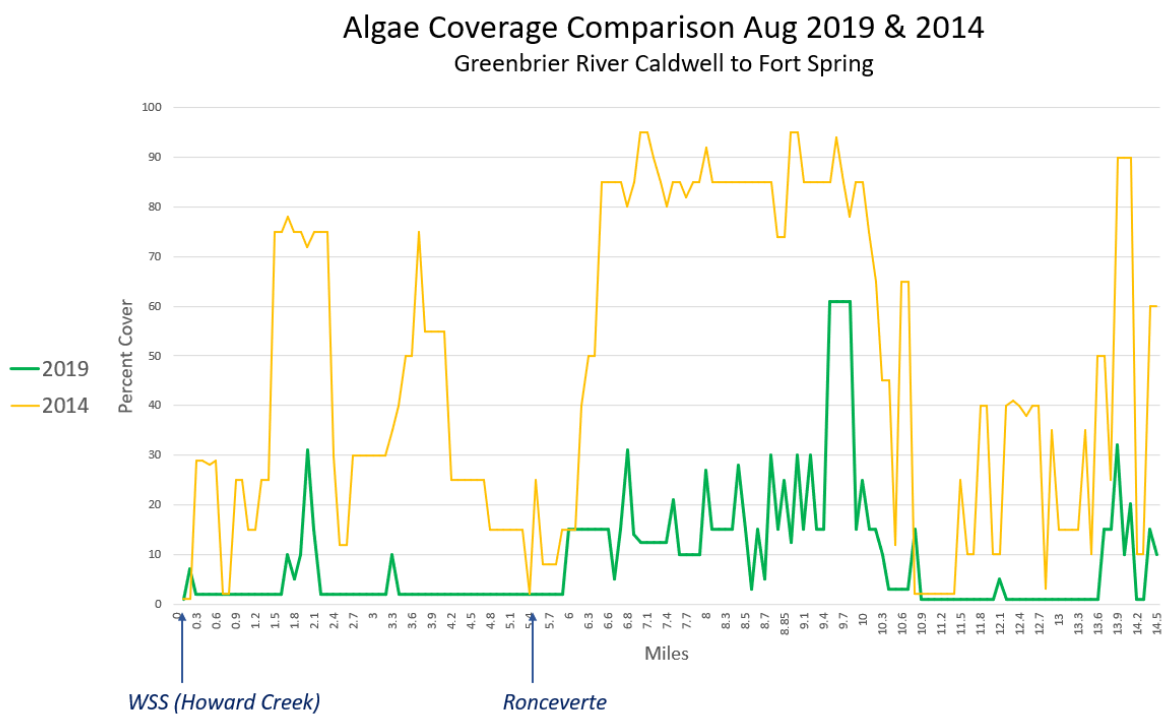

Figure 4. Comparison of algae growth prior to WWTP upgrades with post-upgrade conditions.

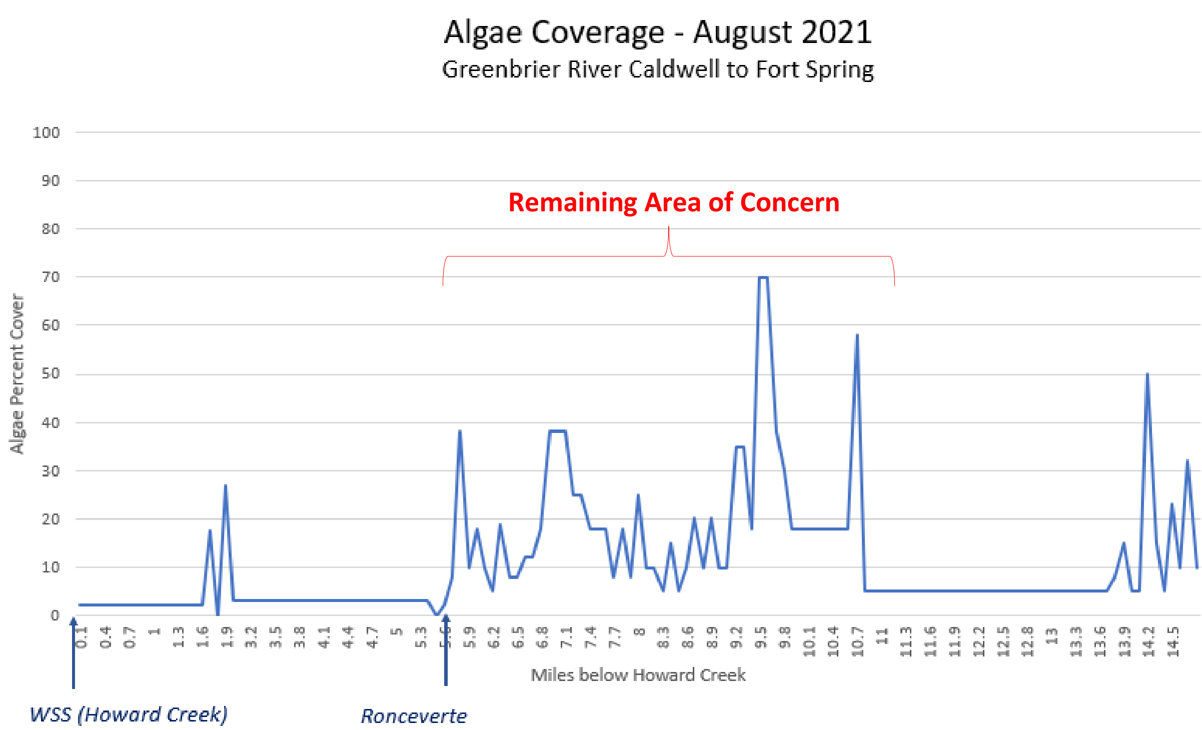

Figure 5. Algae growth (coverage of Greenbrier River) in August 2021 showing remaining impaired area.

This plan originally called for monitoring to be conducted through 2020, which was accomplished, and very positive results were obtained. In 2021 DEP did not perform water quality sampling at the monitoring stations but did do observations at the established monitoring points. Unfortunately, in August 2021 a substantial algae bloom showed up below the Ronceverte WWTP which impacted parts of the river for over 4 miles downstream. (See Figure 5 and Photos 8 and 9.)

Given that the 2021 bloom started immediately below the Ronceverte WWTP discharge, DEP conducted several follow-up visits to the Ronceverte WWTP. DEP also visited the White Sulphur Springs and Alderson WWTPs, and reviewed Discharge Monitoring Report data from all the facilities, as well as USGS flow, DO, and temperature data. The water level in the river was too low (<60 cfs) to perform a longitudinal survey when the bloom was initially observed, and by the time the flow had recovered enough to float the river some of the algae was dying off and the levels had decreased somewhat.

Photo 8. Portion of the Greenbrier River below Ronceverte, showing just over 40% coverage. August 5, 2021

Photo 9. Dying algae in the Greenbrier River below Ronceverte. August 25, 2021

Key observations from this 2021 bloom are listed below:

1. In 2019 the river flow had been lower for a longer period of time without exhibiting a significant bloom, indicating the 2021 bloom was driven by something other than just low flow in the river.
2. The bloom began at the Ronceverte discharge and was confined in the 4-mile segment of river downstream of Ronceverte. Little to no filamentous algae growth was present upstream below White Sulphur Springs or further downstream below Alderson.

The Ronceverte and White Sulphur Springs (WSS) WWTPs are very similar – VLRs with tertiary phosphorous treatment by a chemical feed system and filtration. Reported effluent phosphorous loadings are very similar. However, there are some noteworthy differences which may explain why algae was growing below Ronceverte and not below WSS.

1. WSS adds a poly-aluminum chloride (DelPAC) to precipitate phosphorous, while Ronceverte was feeding alum when the bloom occurred. Ronceverte began adding DelPAC after discussions with DEP representatives on potential ways to further reduce the phosphorous level in their discharge. The bloom's demise occurred within 2-3 weeks, but it is not known if this was the result of the DelPAC addition at Ronceverte or to another factor.
2. WSS's chemical feed rate is controlled by a SCADA system which samples the clarifier effluent for phosphorous at 5-minute intervals and adjusts the chemical feed rate automatically based on the phosphorous content of the effluent. Ronceverte analyzes a single grab sample once per day and manually adjusts the chemical feed rate as the operator determines necessary. The level of chemical additive in the tank is checked daily, but the tank is only marked in 100-gallon increments, making accurate feed rate measurements practically impossible.
3. For final effluent filtration, WSS uses a continuously recirculating sand filter and Ronceverte uses cloth filters. It is not known if one is more efficient than another.

Other operational factors at the Ronceverte WWTP that may have affected the 2021 algae bloom below the Ronceverte discharge include:

1. On days when the centrifuge is run to dewater the sludge and/or days when the digestor is decanting, this water is recirculated to the plant headworks. No adjustments in chemical feed rates were typically made to account for the increased phosphorus load.
2. The mixed liquor suspended solids were maintained higher in 2021 than in 2019. The associated older sludge age would create smaller floc particles that are more difficult to settle and filter.
3. Chemical feed rates (alum and DelPAC) may have been higher in 2019 than in 2021; this is particularly true of the DelPAC. However, good records of the amount of alum or DelPAC used by Ronceverte in 2019 were not readily available.
4. Ronceverte adds lime in the first VLR tank to adjust the alkalinity, but this higher pH may not be the ideal range for the alum to most effectively remove phosphorous.

Another potential factor in reconciling the relatively low reported effluent phosphorus values and growth of algae below the discharge point could be that Ronceverte monitors their effluent only once per week for Total Phosphorus using EPA approved methods. It is possible that the once per week monitoring is not frequent enough to adequately represent the effluent quality. A review of Ronceverte's weekly sample results revealed variable results from week to week. For example, in one week Total Phosphorus may be 0.8 mg/L and the following week it might be <0.05 mg/L. While Ronceverte is meeting its permit limit based on 4 times per month sampling, more frequent monitoring would be needed to establish conclusively how long the periods persist when the effluent phosphorous concentrations are elevated above the 0.5 mg/L target value.

Further, Ronceverte's phosphorous treatment efficiency has not increased quite as much as Alderson and White Sulphur Springs. The phosphorous load from WSS and Alderson both decreased by more than 85%. Ronceverte's phosphorus load reductions, though very significant, have been around 70%. Even though Ronceverte has had significant reductions that have resulted in major improvements in the levels of algae growth and the plant effluent is generally meeting its permit limits for phosphorous, there is still room for additional improvements at Ronceverte which could fully alleviate the algae-related impairment of the river.

In regard to other implementation projects in the Greenbrier River watershed, phosphorous concentrations at DEP's background monitoring station on the Greenbrier River upstream of Howard Creek have not shown any measurable improvement since monitoring began. This station was established to account for non-point source contributions from further upstream in the watershed. Given the very low phosphorous concentrations (at, near, or below detection limits) observed at this station, the size of the watershed, and the percentage of watershed that is forested, reductions to non-point nutrient contributions made through small, localized improvements would be hard to detect by water quality samples at these Greenbrier River monitoring station.

DEP's Watershed Improvement Branch, in coordination with the WV Conservation Agency, US Department of Agriculture and local land farmers, made a substantial effort to reduce non-point source pasture runoff in the Kitchen Creek watershed 2009-2021. More than 120 farmers participated in programs to install practices that reduce runoff of sediment, nutrients, and bacteria from livestock operations; these practices included fencing to restrict stream access, armored stream crossings for livestock, heavy use area protection pads, vegetated riparian buffers, nutrient management plans, and prescribed grazing strategies Kitchen Creek is a tributary of Second Creek, which flows into the Greenbrier River about 4 miles downstream of Ronceverte. As with the Greenbrier upstream of Howard Creek, Second Creek is a large enough watershed that significant localized improvements to water quality in smaller tributaries may not be readily discernable at the mouth – which even before the non-point improvements had "non-detect" Total Phosphorous values at critical flow conditions.

During Phase 1 of this restoration plan there have been no expansions of sewer lines to previously unsewered areas of the Greenbrier River watershed. Rather, POTW systems have focused on improved effluent quality, increasing treatment capacity, and reducing spills and overflows to the Greenbrier River.

Table 4. Phase 1 Milestones

Objective	Target Date	Status	Date Achieved
Evaluate river above RM 50.0 verify impairment status under DEP 2013 listing guidelines.	2014-2020	Achieved.	Segment delisted in 2014 cycle; verified by observations 2014-2018.
Establish phosphorous limits and compliance schedule in Alderson, Ronceverte, and WSS NPDES permits.	2014	Achieved	2014
POTW upgrades operational and achieving phosphorous limits.	2016	Delayed but achieved	2017-2018
Evaluate stream impairment status for 5 growing seasons post-upgrade	2016-2020	Delayed but achieved	2022
Full use attainment and delisting of Greenbrier River from Howard Creek to Fort Spring.	2022	Significant restoration of use, but this river segment remains on the 303(d) list.	Majority achieved by 2022.
Full use attainment and delisting of Greenbrier River from Fort Spring to Mouth.	2022	Achieved.	2022

In summary, implementation of Phase 1 has resulted in more than a 90% reduction in the river miles impacted by algae growth. Prior to Phase 1, a full 100 miles of the Greenbrier River were listed as impaired. Only one 14.1 mile long assessment unit remains listed in the draft 2018/2020/2022 303(d) list, with only a 4-mile segment of that assessment unit exceeding DEP's listing threshold and only in some years. Drinking water complaints have been nearly eliminated, and summertime recreational use opportunities are significantly improved in highly utilized segments of the river. Nevertheless, additional improvements are needed at Ronceverte to fully restore use in the one remaining segment of the river that continues to be listed among the state's impaired waters.

Phase 2 (2022-2025)

This restoration plan's adaptive management strategy will continue to develop and incorporate new data and information over the next three years, adjusting and evaluating subsequent implementation actions to meet narrative water quality standards. During this period DEP will:

1. Assess the impairment status of the Greenbrier River from Howard Creek to Fort Spring, monitoring at the Phase 2 sample locations listed in Table 2 and conducting longitudinal surveys at least annually.
2. Evaluate operational procedures at the Ronceverte WWTP and confer with Ronceverte to identify ways to increase efficiency of phosphorous removal.
3. Evaluate the suitability of once per week effluent monitoring (May-October) for obtaining data sufficiently representative of Ronceverte's phosphorous load to the Greenbrier River.
4. Determine any additional actions needed to eliminate violations of water quality standards and provide recommendations addressing sources contributing to any remaining impairment.

If weather and river flow conditions are not conducive for substantial algae growth during the 2023-2025 growing seasons, and such conditions prevent an ample evaluation of progress made toward attainment, DEP may extend Phase 2 up to three more years to continue to monitor progress and impairment status.

Phase 2 Milestones

April 2023	Develop strategy to maximize phosphorus-removal at Ronceverte WWTP during low-flow conditions (<250 cfs) using the existing infrastructure (April 2023), perhaps utilizing stream flow as a trigger to implement additional control strategies.
October 2023	Evaluate operational performance at Ronceverte WWTP, including the removal efficiencies of the various treatment units and chemical additives (alum and DelPAC).
October 2023	Determine if more frequent monitoring should be implemented in Ronceverte's WV/NPDES permit.
May 2024	Make any needed adjustments to Ronceverte's operational strategy, if necessary, and begin implementation.
2023-2025	Collect monthly water quality data and algae measurements at established monitoring stations during algae growing season, and perform at least one longitudinal evaluation of the impaired segment of river annually at a time near the peak of the growing season.

April 2026 Evaluate data collected, including impairment status and use attainment level, and determine next appropriate step(s):

a. Proceed with delisting if full use is restored.
b. Potentially extend Phase 2 monitoring through 2028.
c. Potentially update this plan with additional steps to address point or non-point sources of phosphorous which may be contributing to any remaining impairment.
d. Implement other appropriate actions needed to further understand or address causes of problematic algal growth, should any remain.

Attainment Determination

DEP's 303(d) Listing Methodology for Algae Blooms (Attachment A) specifies the protocol and growth thresholds for identifying impairment caused by filamentous algae blooms. The listing methodology was incorporated in the 2014 WV Integrated Water Quality Assessment and Monitoring Report (Integrated Report) and has been used for determining impairments related to filamentous algae since that time. The original Listing Methodology did not directly address delisting, (i.e., how long and under what circumstances a stream would need to exhibit growth below the stated impairment thresholds before it would be delisted). In the Draft 2018/2020/2022 Integrated Report, DEP described its criteria for removing an algae impaired stream from the 303(d) list.

An algae impaired stream may be delisted if any of the following apply:

- WVDEP has evaluated the stream for impairments of Water Contact Recreation for a period of five consecutive years and found no blooms which would have caused the stream to be listed as impaired for recreational use.

- Specific measures to control algae growth have been implemented, and WVDEP has evaluated the stream for a period of three consecutive years finding no algae blooms causing use impairment.

- For algae impairments related to the Public Water Supply use, when taste and odor complaints associated with algae blooms are alleviated and no treatment beyond "conventional treatment" is required at the drinking water treatment facility for three consecutive years.

These criteria were used by DEP to remove certain algae impaired sections of the Greenbrier River and South Branch of the Potomac River from the Draft 2018/2020/2022 303(d) list. The one assessment unit of the Greenbrier River which remains listed for use impairment caused by filamentous algae will be evaluated using these same criteria.

Attachments

- Attachment A – 303(d) Listing Methodology for Algae Blooms
- Attachment B – Filamentous Algae Monitoring SOP
- Attachment C – Sample Permit Final Limits Page
- Attachment D – DEP 2008 Technical Report
- Attachment E – DEP 2010 Technical Report

Attachment A

303(d) Listing Methodology for Algae Blooms

303(d) Listing Methodology for Filamentous Algae Blooms
WVDEP June 19, 2013[1]

In 2011 the Requirements Governing West Virginia Water Quality Standards (47CSR2) were modified to include language that prohibited algae blooms which impair or interfere with the designated uses of a stream. In order to scientifically define what levels of algae would impair or interfere with the uses of a stream, DEP hired the research firm Responsive Management to survey West Virginians on their tolerance levels for filamentous riverine algae growth. DEP worked closely with Responsive Management to develop the public survey of over one thousand West Virginians in 2012.

West Virginia Residents' Opinions On and Tolerance Levels of Algae in West Virginia Waters found that a clear majority of West Virginians (over 70%) regarded 39% algal cover as impairing their use. Roughly half of the people regarded 26% algal cover as an impairment. Approximately three fourths (72%) of those surveyed indicated that algal cover of 20% would not interfere with their use of the stream.

Other factors related to filamentous algae blooms that will affect the recreational use of a stream include duration of the bloom, frequency of occurrence, filament length, longitudinal extent, percent of water column filled, and location of the bloom relative to houses, camps, and public access sites.

Further, algae blooms may impair other uses of a stream. DEP has determined that algae blooms have at times affected some streams' use as a drinking water supply. Specific guidance is also provided in this document for determining impairment in cases impacting public water supplies (47-2-3.2.d and 3.2.h).

DEP will use the following guidelines to evaluate compliance with the narrative standards and/or determine impairment of a stream's use(s) caused by filamentous algae blooms:

1. A filamentous algae cover of greater than 20% of the lateral transect area will be judged to interfere with the recreational use of a stream whenever that bloom extends for a longitudinal distance greater three times the average stream width in the impacted segment of stream, as determined by a minimum of three stream measurements taken using the SOP for Filamentous Algae Monitoring developed by DEP.

2. Except as provided in Guideline 4, a filamentous algae cover of greater than 40% of the lateral transect area will be judged to interfere with the recreational use of a stream.

3. Whenever a stream has filamentous algae covering more than 20% of a lateral transect area, and the algae bloom is located immediately adjacent to any occupied dwelling, campground, or developed public access site, DEP may determine that the recreational use of a stream is impaired after considering such factors as duration of the bloom, frequency of occurrence, longitudinal extent, bloom location relative to the stream access site, level of use, type of use, length of filaments, and size of floating mats.

[1] Amended November 1, 2016 and March 1, 2022.

4. Isolated bloom events include those that are isolated temporally, longitudinally, and/or geographically. DEP *may* determine a stream is not impaired when an *isolated bloom event* exceeds Guidelines 1-2. In making such a determination DEP will consider the duration of the exceedance, lifespan and physical characteristics of the algae, longitudinal extent, and percent of the water column filled. Additionally, DEP will consider available information regarding the flow conditions during the year of the bloom relative to the normal range of flows[2], location of the bloom relative to other algae blooms, types of access and recreational uses, public complaints, frequency of occurrence and intensity of the bloom in previous years.

5. Guidelines 1-3 *DO NOT* apply where the width of a stream (at the ordinary high water mark) is less than 15 meters wide, or when algae filaments or stalks are less than 5 cm. Guidelines 1-3 are intended only for nontoxic filamentous algae blooms and do not address, for example, growth of non-filamentous periphyton, sestonic algae blooms, or bloom events involving toxic or otherwise harmful algae. This is not to say that these blooms could not ever impair a stream; only that these blooms are beyond the scope of this guidance.

6. Relating to filamentous or any other algae blooms causing taste or odor that interferes with the use of the water and/or causing additional (unreasonable) treatment to be required at drinking water plants, DEP considers any treatment beyond "conventional treatment" (see 47-2-2.1) that is required as a result of taste and/or odor complaints associated with algae blooms to be grounds for classifying a stream as impaired (47-2-3.2.h). DEP will also judge a stream to be impaired under 47-2-3.2.d whenever multiple taste or odor complaints about finished drinking water are documented during the algae growing season, regardless of whether any additional treatment beyond conventional treatment is being performed at the drinking water plant.

Rationale for Guidelines

The guidelines developed by DEP for determining impairment represent a balanced, rational, and scientific approach to maintaining the recreational use of streams that are impacted by filamentous algae blooms.

1. DEP interprets the Responsive Management study to demonstrate that use of a stream is not impaired by an algal coverage of less than 20%.

2. In the Responsive Management research, 49% of all people surveyed and 52% of boaters (the most sensitive user group) indicated that a 26% algal coverage of stream would interfere with their use of the stream. This level of algal development represents the "tipping point" for the majority of people. However, *a stream condition in which half the users find it to be impaired can hardly be considered to be fully meeting its designated uses*. Therefore, DEP is setting the standard for this guideline at a more protective level. The Responsive Management survey found that when the coverage was

[2] Low flow events do not negate the narrative standard; but an evaluation of the flow compared to other years may give an indication of the frequency that similar bloom events might be expected to occur.

reduced to from 26% to 20%, 3 in 4 people found it to be acceptable. This slightly lower standard provides protection for another quarter of users.

Recognizing that 20% coverage at a single transect on a stream would not necessarily impair the use of a stream in all cases, additional guidance on the longitudinal component is provided. Guideline #1 provides an allowance for 20-40% algal coverage for a distance up to three times the average width (between the ordinary high water marks on the banks) of the stream segment. Given the special consideration provided for dwellings, campgrounds, and public access sites in Guideline #3, the longitudinal allowance is meant to provide a reasonable limit to the distance that boaters and fisherman would encounter potentially undesirable levels of algae. The length of the longitudinal component is also a practical limit to what can typically be assessed without having to use a boat in the assessment.

3. Guideline #2 establishes a general "ceiling" for algae cover on a stream. It is made necessary especially by the longitudinal allowance given in Guideline #1 (3X river width). For example, a 200 foot wide river with 22% bottom cover may still be considered acceptable for wading and fishing if the bloom persists even for 500 feet, but use of a river that is 80% covered by algae for 500 feet is impaired significantly. There needs to be some upper limit for this longitudinal allowance. There is near universal agreement[3] that 47% coverage impairs use of a stream. The ceiling established by this guideline (40% coverage) establishes a reasonable limit to the amount of algae that can cover a stream in the longitudinal allowance provided in Guideline #1.

4. Most boaters and fisherman are mobile river users, often floating stream reaches several miles in length, where a moderate algae bloom (of limited magnitude as prescribed in Guidelines 1 and 2) would not significantly impact their use. However, DEP recognizes that special consideration may be needed for river uses associated with fixed locations like residences or a public access sites. A property owner should be able to utilize the river bordering his property and all should be able to utilize the stream at public access sites. .

   Implementation of Guidelines 1 and 2 may result in a limited distance algae bloom, considered unacceptable by the majority, to overlap fixed use locations. As such, Guideline #3 provides flexibility to determine use impairment associated with algae coverage of magnitudes less that the thresholds established in Guidelines 1 and 2 when the impacted zone is located adjacent to dwellings, campgrounds, or developed public access sites. Whenever the coverage exceeds 20% at these sites, DEP may make a site specific determination of use impairment after considering the described factors.

5. The severity of an algae bloom may be measured in essentially four dimensions: lateral coverage (width), longitudinal extent (length), water column fill (depth), and duration (time). As any of the dimensions increase the bloom would be considered more severe; and as any of the dimensions

[3] The Responsive Management study found that 87% of all people surveyed indicated that a 47% algal coverage in a stream's transect would interfere with their use of a stream.

decrease the bloom would be considered less severe. Guidelines 1-2 are primarily concerned[4] with only one of the dimensions – lateral coverage – since this was the dimension evaluated by the public survey. Guideline 4 establishes a mechanism by which DEP has a limited degree of flexibility in considering these other dimensions and variables, when an isolated algae bloom occurs.

Guideline 4 applies ONLY to "isolated bloom events". These blooms are isolated temporally, longitudinally, and/or geographically. For example, DEP may evaluate 10 miles of a river and encounter an isolated algae bloom covering 42% of the river and extending for only 50 feet. A strict application of Guideline 2 would deem the recreational use of this river impaired. Consider also that the bloom may be a species of algae with a shorter life span, which results in a short lived bloom that peaked above the listing threshold for only 5-7 days. Crafting guidelines to specifically address every possible variable would result in a lengthy, complicated set of Guidelines. Instead, DEP has opted to provide some room for flexibility and professional judgement in those very limited circumstances where an isolated bloom event occurs.

6. The Responsive Management survey only utilized photos of moderate to large river with long strand filamentous algae blooms to determine tolerance levels of algae coverage in a stream. Applying the results of this study to other types of algae, or to smaller streams, would not be appropriate. Periphyton, for example, could cover 100% of a stream bottom without interfering with the recreational use of the stream.

7. Algae blooms, and particularly the decomposition of algae, can cause a strong musty, earthy, or grassy odor in drinking water. This odor is not removed during conventional drinking water treatment processes (sedimentation, filtration, and disinfection) and causes a similar taste in the finished drinking water. The odor and taste issues associated with algae blooms are often attributed to the presence of geosmin and MIB (2-Methylisoborneol), which can be smelled at a very low (parts per trillion) level. To reduce the unpleasant taste and odor caused by the algal blooms, activated carbon is often used as an absorption media; potassium permanganate may also be added as an oxidizing agent to reduce odor. Each of these chemical additives is removed during the treatment process prior to delivery of treated water supply.

   47CSR2-3.2.d lists "Taste or odor that would adversely affect the designated uses of the affected waters" as a Condition Not Allowable in state waters. Whenever the characteristic taste or odor complaints are received about water supplied from systems where the intake is located within or immediately downstream of the zone of an algae bloom, and there is an indication that the odor is caused by the algae bloom, DEP may classify the stream as impaired whenever such complaints are received – regardless of whether they are corrected by the addition of chemicals to the treatment process.

   Taste and odor complaints are not limited to filamentous algae blooms, but can also be associated with sestonic algae, phytoplanktonic algae, or algal periphyton.

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[4] Guideline 1 does address longitudinal extent of blooms in some circumstances.

Listing and Delisting Decisions

If DEP determines that the use of a stream has been impaired in the same segment (Assessment Unit) for two consecutive years, or two out of three years, DEP will include that stream segment in the Section 303(d) List of Impaired Streams West Virginia.

A stream which has been placed on the state's 303(d) List of Impaired Streams due to algae blooms may after a time no longer exhibit such blooms. This may be due to various factors such as changes in causative sources (treatment plant upgrades, BMP implementation, etc.), changes in stream chemistry (particularly alkalinity or hardness), and/or physical alterations (natural or manmade). DEP will not consider delisting a stream when the diminished algae growth is due primarily to an annual variation in rainfall, i.e., excessive rainfall and streamflow during the algae growing season that lessens the severity of algae blooms will not be considered grounds for removing a stream from the

For a stream which was previously listed under these guidelines because of impairment of the stream's recreational use, DEP will consider removing a stream from the 303(d) list when one of the following conditions are met:

1. DEP has evaluated the extent of algal growth during critical flow conditions in locations historically susceptible to blooms for a minimum of five consecutive years and found no blooms which would have caused the stream to be listed as impaired for recreational use.
2. Specific measures have been implemented to significantly reduce nutrient loading from known causative sources, or which otherwise work to control the growth of algae, and DEP has evaluated the extent of algal growth during critical flow conditions in locations historically susceptible to blooms for a minimum of three consecutive years. During the three years of evaluation, no blooms were observed which would have caused the stream to be listed as impaired.

DEP will consider removing a stream from the 303(d) list which was previously listed under these guidelines because of impairment of the stream's use as a drinking water source when:

1. For a period of three consecutive years, taste and odor complaints associated with algae blooms are alleviated and no treatment beyond "conventional treatment" (see 47-2-2.1) is required at the drinking water treatment facility.

Attachment B

Filamentous Algae Monitoring SOP

CHAPTER 1. FILAMENTOUS ALGAE MONITORING

Filamentous Algae Overview

Since 2007, the Watershed Assessment Branch (WAB) has devoted much effort and resources to evaluating the causes, locations, and severity of filamentous algae blooms in West Virginia's streams and rivers (***see Figure 8-1 below***). As part of that effort, WAB has measured the development of filamentous algae blooms at various locations and reported the results as "percent algae cover" and occasionally "percent water column fill". Percent algae cover is the percent of the stream bottom covered by filamentous algae at a measured transect of the stream, and percent water column fill is the percent of the water column filled in a cross-sectional view of the stream at a given transect location. It should be noted that neither of these measurements have a longitudinal component; *i.e.*, these two measurements do not account for the length of stream reach impacted by filamentous algae.

Figure 8-1. A filamentous algae bloom on the Tygart River upstream of Norton, June 2012.

WAB has developed a method for measuring filamentous algae in streams based on the methods described in the following:

Morgan, A.M., T.J. Royer, M.B. David, and L. Gentry. 2006. Relationships among nutrients, chlorophyll-a, and dissolved oxygen in agricultural streams in Illinois. *Journal of Environmental Quality* **35**: 1110-1117.

Schaller, J.L., T.V. Royer, and M.B. David. 2004. Denitrification associated with plants and sediments in an agricultural stream. *Journal of the North American Benthological Society* **23**: 667-676.

At a given stream transect, a measuring tape is str*etc*hed across the stream; wetted width and portions (or segments) of the stream covered by filamentous algae are recorded. On occasion, WAB may also make an additional measurement of the filamentous algae thickness along the transect segments so that the amount of water column impact, not just stream cover, can be calculated.

This method was first used as a basis for filamentous algae measurement in West Virginia beginning in the fall 2008 in four priority river watersheds: Greenbrier River, Cacapon River, Tygart Valley River, and South Branch of Potomac River. In 2014, additional components to document submerged aquatic vegetation, canopy cover, and stream bearing were added.

Filamentous algae blooms tend to appear mostly during the summer months due to several factors including: flow induced high nutrient concentrations (*e.g.*, low flow), higher air temperatures, and longer photoperiods (*i.e.*, day lengths). Because of this, sampling has typically been constrained to this time period. However, filamentous algae blooms can appear under other conditions (*e.g.*, in the Early Spring due to a lack of competition for light before full canopy leaf-out and increasing air temperatures).

The procedure below represents a summary and explanation of the method used by WAB to determine the “percent algae cover” and “percent water column filled” by filamentous algae. It is set forth both to serve as WVDEP’s recommended standard measuring method for future measurements of filamentous algae blooms, both by WAB and by others wishing to make measurements comparable to those made by WAB.

The Filamentous Algae Monitoring Program utilizes some of the same sampling protocols of other Watershed Assessment Branch programs. Specifically, the SOP sections that apply to this program are as follows:

CHAPTER 2. INSTRUCTIONS FOR ASSESSING THE STREAM SITE (INCLUDING SETTING UP THE SITE, SITE DOCUMENTATION, AND GUIDELINES FOR COMPLETING THE STREAM ASSESSMENT FORMS) Section C. Guidelines for Completing the Stream Assessment Forms on page 2-28

CHAPTER 3. WATER COLLECTION PROTOCOLS starting on page 3-1

CHAPTER 14. Section A. Blanks and Duplicates starting on page 14-1

Materials and Supplies

> **IMPORTANT:** ***The unit of measurement can be either in feet (marked in tenths of a foot) or meters, but the units must be the same for both the distance and depth.***

1. 100 meter Tape Measure – Units can be in either tenths of a foot (rather than inches) on one side and meters on the other. It is recommended to use some sort of stakes or pins (*e.g.*, steel rebar) to easily anchor each end of the tape.
2. Vertical Measurement Device – To be used only if calculating the “percent water column fill. A stiff vertical device such as a wading rod, thalweg pole, or surveyor rod marked in either tenths of a foot or meters. Other non-flexible measuring instruments (such as a yard stick with feet marked in **inches**) can be used if absolutely necessary, but the measurements will need to be converted to tenths of a foot before calculating any of the formulas below. Experience has shown that the use of more flexible metal measuring tapes are not suitable to measure water depth whenever there is significant water velocity in the stream.
3. Camera – to take photos of the transect area’s algae cover
4. Filamentous Algae Measurement Form

Field Safety Precautions

Since this procedure often occurs on large streams and rivers, deep and swift water safety precautions (like the use of personal floatation devices) should be observed.

Part 1. Field Sampling Procedures

Site Selection

Basic guidelines for site selection.

1) **Site should be wadeable with some depth, but not too deep.**
If possible, select a stream measurement transect that may be waded comfortably and safely. Streams varying from one to three feet deep are ideal. Streams which are too deep to comfortably and safely wade may result in measurement

inaccuracy because so much effort is required to simply stay on one's feet. Also, deeper water decreases light penetration into the water, which tends to inhibit the development of algae growth. This may skew results if the measurer is looking for trends at different locations along a given stream.

2) **Site should have rocky substrate with minimal transient material (*i.e.*, fine sediments like silt, sand, and fine gravel).**
Growth of filamentous algae also tends to be inhibited by the lack of rocky substrate. So again, if possible, select measurement sites with little or no sediment accumulation to avoid skewing results in comparative studies.

3) **Sites in narrower streams should have a moderately open canopy.**
For narrow streams, shading from the tree canopy overhead can have an inhibitory effect on algae growth similar to that of streams that are too deep.

4) **Avoid sites that will potentially have a dry bar during low flow situations**. This may not easily be determined during higher flows, but any attempt to avoid this will make the calculations easier later.

Transect Selection

Basic guidelines for transect selection within a site.

1) **Level of algae growth**. Due to factors discussed above and other physical variables, the level of algae growth may vary considerably at a given location. When correlating the level of algae growth with stream chemistry, select a transect location that is representative of the general site location. If possible, avoid areas with fast currents or deep pools as this may interfere with algae growth.

2) **Return visits**. If the site is intended to monitor changes in algae growth over a period of time, the same transect location should be used for each visit. The exact transect location should be documented (drawing, photo, marked in the field or on the bank in some semi-permanent fashion) so that it can be consistently repeated for comparability.

Establishing the Transect

Determine the wetted width of the stream by stretching the tape measure across the stream perpendicular to the stream banks. Secure the tape on each stream bank, pulling it tight enough to minimize sag (*i.e.*, a sag in the tape will give a wider wetted width measurement than really exists). Wide rivers may necessitate variations of measuring instrument and logistics, such as using an accurate laser range finder or pulling a measuring tape across the river in sections at a time. However, the basic concept will remain the same.

A minimum of five algae measurement segments should be recorded for each transect across the stream channel. For example, a stream that is 200 feet wide would require at least five 40 foot (5 x 40 = 200) segments across the stream where the algae growth is measured. As you traverse the stream channel while setting up the tape measure, make some notes about where the minimum five segments should be placed. Segments should be placed to document and define areas with or without algae mats, significant changes (> 0.5 feet or 0.15 meters) in amount of algae growth (both in percent cover and thickness) on the stream bed, and/or sudden changes in depth. For example, if the 200 foot stream in the previous example had a flow (or thalweg) channel that was only 10 or 15 feet wide and deeper than the rest of the stream, the flow channel should be treated as a separate segment in the stream transect as it is most likely conveying water all year long and will represent a fixed segment in trend measurements (***see Segment 3 in the Figure 8-2 below***). Conversely, segments can be lengthened in areas where the water depth and algae growth are more uniform. Additional segments may be added to the transect while taking measurements and the stream bottom is more thoroughly investigated.

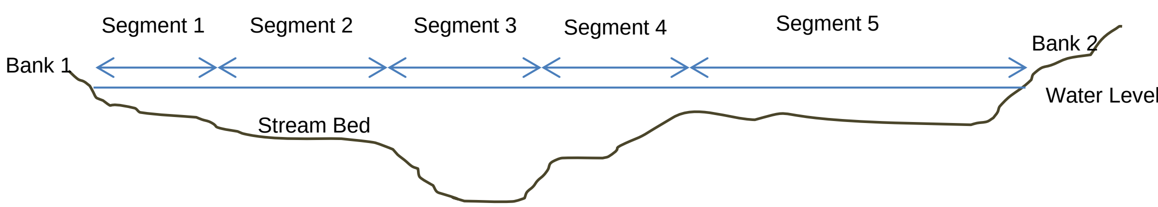


Figure 1-1. Hypothetical example of stream segments across a filamentous algae

NOTE: This concept of isolating differing sections laterally across a stream channel is used in the Flow measurement methodology in *CHAPTER 4. STREAM FLOW MEASUREMENT PROTOCOLS starting on page 4-1*and longitudinally in the Dominant Substrate/Reach Characterization in *CHAPTER 2. INSTRUCTIONS FOR ASSESSING THE STREAM SITE (INCLUDING SETTING UP THE SITE, SITE DOCUMENTATION, AND GUIDELINES FOR COMPLETING THE STREAM ASSESSMENT FORMS)Section C. PAGE 3. Dominant Substrate Type and Reach Characterization on page 2-52*.

<u>Documentation using the Filamentous Algae Monitoring Form</u>

Record the site documentation information on the Filamentous Algae Monitoring Form as outlined in **CHAPTER 2. INSTRUCTIONS FOR ASSESSING THE STREAM SITE (INCLUDING SETTING UP THE SITE, SITE DOCUMENTATION, AND GUIDELINES FOR COMPLETING THE STREAM ASSESSMENT FORMS) Section C.**

PAGE 1**. Site Verification on page 2-30.**

Information includes:

- PAGE 1: Stream name, ANCode, and Location (*e.g.,* Greenbrier River at I-64 East bridge.), Coordinates of the waters sample location (x-site) and, if the stream is excessively wide, coordinates where the transect ends (***see Figure 8-3 below***), Site Map, *etc*.

Field Lat X-site	N	**Field Lon X-site**	W
LDB Transect Lat	N	**LDB Transect Lon**	W
RDB Transect Lat	N	**RDB Transect Lon**	W

Figure 8-3. Example of additional Transect LDB and RDB Coordinate Boxes on PAGE 1

- PAGE 2: Field Water, Periphyton/Algae/Aq. Plant Info, Canopy Density. An additional section to document the canopy density along the stream transect (***see Figure 8-4 below***).

Canopy Density (Densiometer) Readings: 0-17 Possible per reading; Hold 1ft (0.3 m) above surface of water									
Left		Left Middle		Center		Right Middle		Right	
Up		Up		Up		Up		Up	
Left		Left		Left		Left		Left	
Down		Down		Down		Down		Down	
Right		Right		Right		Right		Right	

Figure 8-4. Example of the additional Canopy Density (Densiometer) Readings Section on PAGE 2

- PAGE 3: Filamentous Algae Measurements (***see Figure 8-6 on next page and Taking Filamentous Algae Measurements on page 8-8***)

- PAGE 4: Landowner/Stakeholder Information, Recon, & Photos. Additional options to document Houses, Campgrounds/Campsites, Public and Private Stream Access are provided under the Recon/Accessibility section in this version of the form (***see Figure 8-5 below***).

Discuss the accessibility to the site including accessibility, posted property, fenced, beside road, long walk over treacherous terrain, hike length, 4 x 4 needed, get key from landowner, etc.	
Check all that apply:	☐ Easy Access ☐ Difficult Access ☐ Public Property ☐ Private Property ☐ Posted ☐ Fenced ☐ Gated ☐ Get Key from Landowner ☐ Beside Road ☐ Short Hike ☐ Long Hike ☐ 4x4 Needed ☐ Houses ☐ Campgrounds/Campsites ☐ Public Stream Access ☐ Private Stream Access ☐ Other (explain)
Recon/Accessibility Notes:	

Figure 8-5. Example of the expanded Recon/Accessibility Section on PAGE 4

FILAMENTOUS ALGAE MEASUREMENTS>>>>>>>>>>>>>>>>>>>>>>>>>>>>>	Reviewers Initials	
AN-Code: PSB-(12.1)	Date: 5/30/2014	
Measurer: John Doe	Time: 1625	

Location & Bank	D_{Begin}	D_{End}	Water Depth (WD_i)	% SAV Cover	% Algae Cover (AC_i)	Algae Thickness (AT_i)	Segment Dominant Substrate Type	Segment Measurement Notes
$Bank_1$		0.5						LDB ■ RDB ☐
Segment 1	0.5	2.6	0.5	0	25	0.2	CB	
Segment 2	2.6	4.9	1.1	5	50	0.4	CB	
Segment 3	4.9	8.9	0.4	5	50	0.3	BL	
Segment 4	8.9	12.5	0	0	0	0	BR	
Segment 5	12.5	14.2	0.5	0	75	0.4	FG	
Segment 6	14.2	18.2	1.5	5	75	0.4	CB	
Segment 7	18.2	22.6	1	15	45	0.2	FG	
Segment 8	22.6	24.5	0.4	10	35	0.1	SA	
Segment 9								
Segment 10								
Segment 11								
Segment 12								
Segment 13								
Segment 14								
Segment 15								
Segment 16								
Segment 17								
Segment 18								
Segment 19								
Segment 20								
$Bank_2$		24.5	DS Channel Orientation/Bearing		319^0	Measurement Units Feet ■ Meters ☐		LDB ☐ RDB ■

Substrate Particles	Particle Codes	Size Class	Substrate Particles	Particle Codes	Size Class
Bedrock	BR	Smooth surface rock/hardpan (>4000 mm –bigger than a car)	Fine Gravel	FG	Ladybug to marble (>2-16 mm)
Boulder	BL	Basketball to car (>250-4000 mm)	Sand	SA	Gritty – up to ladybug (>0.06-2 mm)
Cobble	CB	Tennis ball to basketball (>64-250 mm)	Silt & Fines	ST	Fine – not gritty (<0.06 mm)
Coarse Gravel	CG	Marble to tennis ball (>16-64 mm)	Clay	CL	Slick/ hard clay or hard-pan clay

Page 3 WVDEP WAB Filamentous Algae Monitoring Form (5/30/2014)

Figure 8-6. Example of PAGE 3 of the Filamentous Algae Monitoring Form

Taking Filamentous Algae Measurements

Fill out PAGE 3 of the Filamentous Algae Measurements Form using the following steps:

1. Determine the downstream channel orientation by taking a bearing measurement (*e.g.*, 0^0 being a stream flowing due North; 90^0 being a stream flowing due East; 180^0 being a stream flowing due South; 270^0 being a stream flowing due West; 315^0 being a stream flowing Northwest). Record this value near the bottom center of the page.

2. Indicate what the selected measurement units will be (*i.e.*, Feet or Meters) near the bottom center of the page.

3. On the first or starting Bank ($Bank_1$), record the measurement at the stream channel's or wetted edge as the initial point ($Bank_1$ D_{End}). Check in the note field whether this is the left descending bank (LDB) or right descending bank (RDB). This same measurement for the bank ($Bank_1$ D_{End}) should also be recorded as the beginning measurement for the first cross segment (1 D_{Begin}). The D_{End} measurement for each segment will be the D_{Begin} measurement for the next segment.

4. Wade into the stream observing the water depth, submerged aquatic vegetation, filamentous algae percent cover or depth, and algae mats. If there are significant changes in any of these conditions before reaching the approximate predetermined segment width, define the end of the segment and record the distance on the tape measure that corresponds to the end of the first segment (1 D_{End}). Again, the D_{End} for each segment then becomes the D_{Begin} for the next segment.

5. Within that segment, record the representative water depth (WD_i), estimated percent stream bottom submerged aquatic vegetation (SAV) & filamentous algae cover (AC_i), the representative algae thickness (AT_i) (if necessary), and the Dominant Substrate Type.

   > **<u>IMPORTANT</u>:** ***Remember that large variations in water depth (>0.5 feet or >0.15 m) or algae growth should cause the start of a new segment.***

   a. <u>Water depth (WD_i)</u> is determined by evaluating a given transect segment for a representative depth measurement.

   b. The <u>percent submerged aquatic vegetation (SAV)</u> and <u>percent filamentous algae cover (AC_i)</u> for the segment can only be visually estimated. Carefully observe the stream bottom (both the stream substrate and SAV/filamentous algae present) in a **<u>one unit wide</u>** area (centered on the transect tape measure either in feet or meters) for the entire length of the segment. Estimate and record the percent of the stream bottom in the segment that is covered with submerged aquatic vegetation and filamentous algae growth respectively. "Covered" means that SAV or algae are present and visually obscuring the stream bottom. The SAV or algae may not necessarily be attached to the stream bottom within the one foot wide area. For example, algae may only be attached to 40% of the stream bottom in the one foot wide segment, but long strands of algae may extend down from upstream and cover 80% of the stream bottom within the transect area. ***See Figure 8-7 to Figure 8-19 for photo examples of measured percent filamentous algae cover***.

Figure 8-7. 3% Filamentous Algae Cover

Figure 8-8. 4 % Filamentous Algae Cover

Figure 8-9. 12% Filamentous Algae Cover

Figure 8-10. 15% Filamentous Algae Cover

Figure 8-11. 20% Filamentous Algae Cover (Short Strands)

Figure 8-12. 20% Filamentous Algae Cover (Long Strands)

Figure 8-13. 26% Filamentous Algae Cover

Figure 8-14. 35% Filamentous Algae Cover (Short Strands). Note that this is the same location as Figure 8-15.

Figure 8-15. 38% Filamentous Algae Cover (Long Strands). Note that this is the same location as Figure 8-14.

Figure 8-16. 39% Filamentous Algae Cover

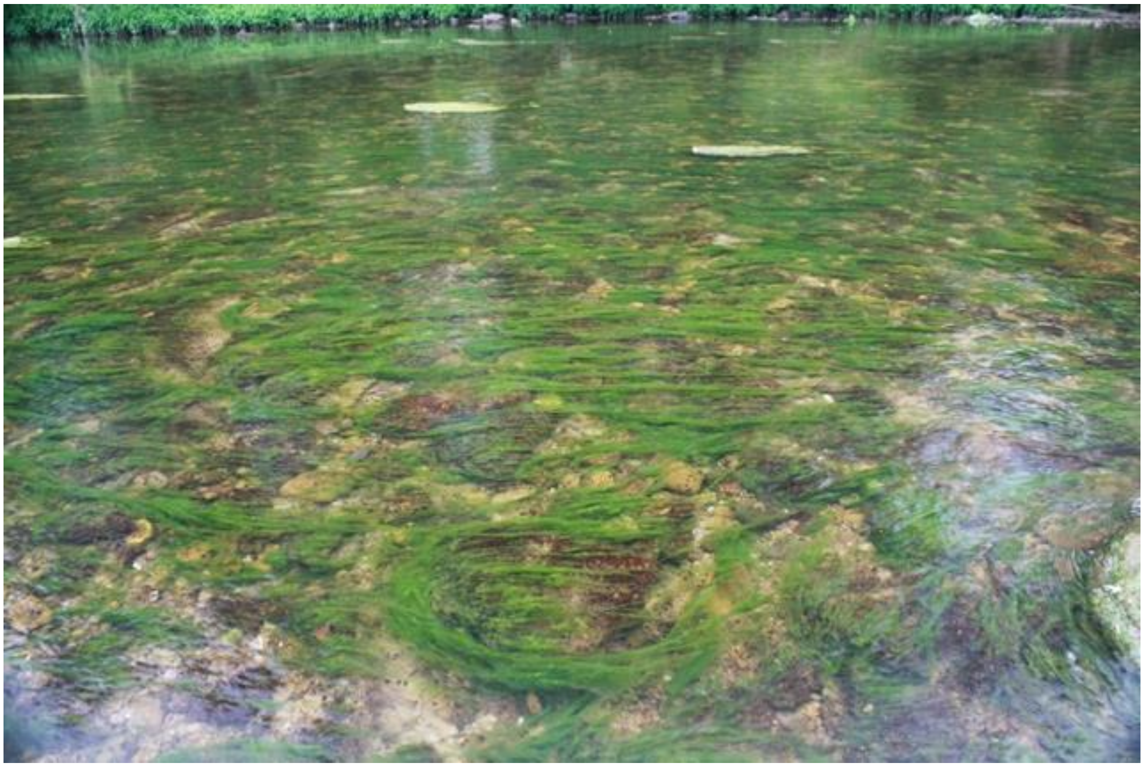


Figure 8-17. 47% Filamentous Algae Cover

Figure 8-18. 65% Filamentous Algae Cover

Figure 8-19. 98% Filamentous Algae Cover

c. Algae Thickness (AT_i) is determined by evaluating the given transect segment for a representative algae thickness measurement. Thickness measurements are made to determine how much of the water column is filled by filamentous algae in relation to the water depth. Length of the filaments is not a primary concern here; only how much of the vertical water column is filled with algae. If algae mats are present, the recorded algae depth is determined by adding the depth of the algae mat to the depth of the algae growing on the stream bottom. Mats may need to be moved out of the way to observe the bottom layer of algae attached directly to the stream bottom. REMEMBER: Algae Thickness should never be more than the water depth.

d. Dominant Substrate Type is determined by observing the predominant substrate size particle for the segment and using the classification table at the bottom of PAGE 3 ***(Figure 8-6 above)***.

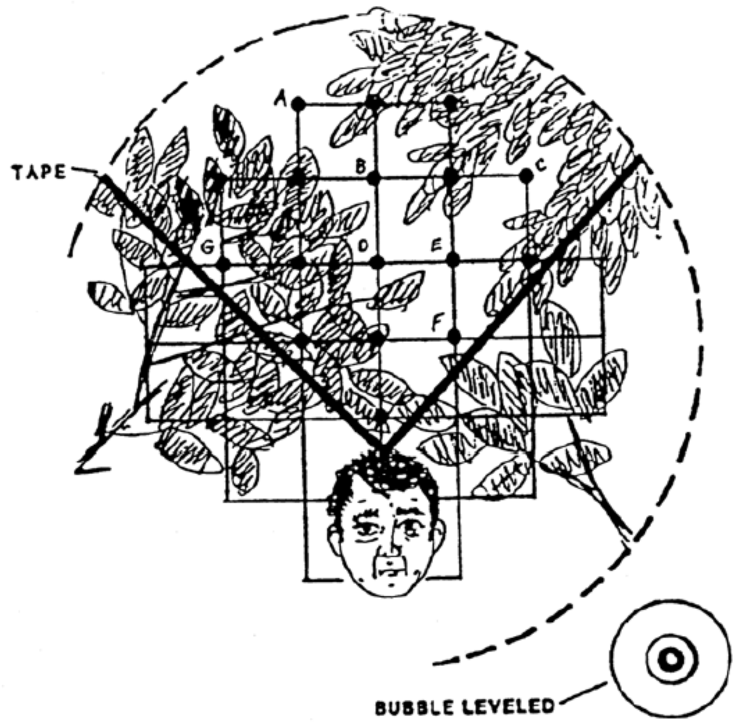
6. Repeat steps two and three with each progressing segment of the transect.

7. If you encounter a mid-stream dry bar (not underwater) then document the bar width as its own segment (using the wetted edges of the bar as D_{Begin} and D_{End} for the segment) and make a note on the form. This area will be excluded from the calculation later.

8. When the far bank ($Bank_2$) is reached, record the final tape measurement distance at the wetted edge ($Bank_2$ D_{End}) and note LDB or RDB in the note field.

Measuring Canopy Density with a Densiometer

Canopy Density is measured based on a method used in the USEPA's National Rivers and Streams Assessment (NRSA), which is an element of the National Aquatic Resources Survey (NARS). Measurements are made using a spherical densitometer (model A-convex type) that is modified with a permanent marker or tape ***exactly as shown in Figure 8-20 on next page***.



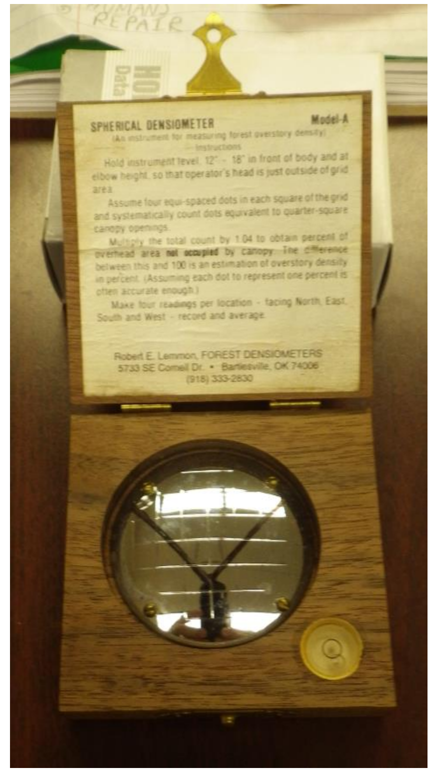


Figure 1-2. Examples of Modified Convex Spherical Canopy Densiometer (from Mulvey et al.

The markings or tape will limit the number of square grid intersections to 17 and densiometer readings can range from 0 (no canopy cover) to 17 (maximum canopy cover). Four measurements are obtained at each of 5 equidistant locations along the cross-section transect: Left (at the water's edge on the Left Descending Bank), Left Middle, Center, Right Middle, and Right (at the water's edge on the Right Descending Bank).

Fill out the bottom of PAGE 2 (***see Figure 8-4 on page 8-6***) of the Filamentous Algae Measurements Form using the following steps:

1. At the first location on the cross-section transect, stand in the stream and face upstream.
2. Hold the densiometer 0.3 m (1 ft.) above the surface of the stream. Level the densiometer using the bubble level. Move the densiometer in front of you so your face is just below the apex of the taped "V".
3. Count the number of grid intersection points within the "V" that are covered by a tree, a leaf, or a high branch. Record the value (0 to 17) in the Up field for the given location of the cross-section transect on the bottom of PAGE 2 under the Canopy Density section.
4. Face toward the left bank (left as you face downstream). Repeat Steps 2 and 3, recording the value in the Left field for the given location of the cross-section transect on the data form.

5. Repeat Steps 2 and 3 facing downstream and facing the right bank (right as you look downstream). Record the values in the Down and Right fields given location of the cross-section transect on the data form.
6. Repeat Steps 1 through 5 at for the remaining locations on the cross-section transect.

Part 2. Filamentous Algae Data Analysis

Use the following equations to calculate the Percent Algae Cover and Percent Water Column Algae Fill. ***See Figure 8-6 on page 8-7 for data used in the example calculations.***

Calculating Percent Algae Cover

1. Calculate the transect wetted width (WW) by subtracting $\mathrm{Bank}_1\mathrm{D}_{End}$ from $\mathrm{Bank}_2\mathrm{D}_{End}$.

$$\mathrm{WW} = \mathrm{Bank}_2\mathrm{D}_{End} - \mathrm{Bank}_1\mathrm{D}_{End}$$

$$e.g., \mathrm{WW} = 24.5 - 0.5 = 24.0$$

   If any dry bars or islands were measured in the transect, add up their individual widths (Dry_i) and subtract from WW calculated above to get an algal habitat width of the stream transect.

$$\mathrm{AHW} = (\mathrm{Bank}_2\mathrm{D}_{End} - \mathrm{Bank}_1\mathrm{D}_{End}) - \sum(\mathrm{Dry}_1, \mathrm{Dry}_2, \mathrm{Dry}_3, \dots, \mathrm{Dry}_i)$$

$$e.g., \mathrm{AHW} = (24.0) - 3.6 = 20.4$$

2. Calculate the width of each segment (W_i) by subtracting $\mathrm{D}_{Begin\ i}$ from $\mathrm{D}_{End\ i}$.

$$\mathrm{W}_i = \mathrm{D}_{End\ i} - \mathrm{D}_{Begin\ i}$$

$$e.g., \mathrm{W}_1 = 2.6 - 0.5 = 2.1$$

3. Calculate the distance weighted algal cover of each segment (wAC_i) by multiplying the width of each segment (W_i) by the estimated percent bottom algae cover of that segment (AC_i) and divide by 100.

$$\mathrm{wAC}_i = \mathrm{W}_i \text{ x } \frac{\mathrm{AC}_i}{100}$$

$$e.g., \mathrm{wAC}_1 = 2.1 \text{ x } \frac{25}{100} = 0.525$$

Any segment that was a dry bar (DB_i) should be calculated with the Algae Cover (AC_i) as 0.

$$e.g., \mathrm{wAC}_4 = 3.6 \text{ x } \frac{0}{100} = 0$$

4. Calculate the Estimated Percent Algae Cover (PAC) for this transect by dividing the sum of the distance weighted covers by the algal habitat width (AHW) and multiply by 100.

$$\mathrm{PAC} = \frac{\sum(\mathrm{wAC}_1, \mathrm{wAC}_2, \mathrm{wAC}_3, \ldots, \mathrm{wAC}_i)}{\mathrm{AHW}} \text{ x } 100$$

$$e.g., \mathrm{PAC} = \frac{0.525 + 1.15 + 2.0 + 0 + 1.275 + 3.0 + 1.98 + 0.665}{20.4} \text{ x } 100 = 51.9$$

Calculating Percent Water Column Filled

1. Calculate the volume of water in each segment (VW_i) by multiplying the width of each segment (W_i) (*from calculation 2 above*) by the water depth in in segment (WD_i). The third dimension of the volume is the one unit (foot or meter) wide area along the transect segment, effectively multiplying the equation by 1.

$$\mathrm{VW}_i = \mathrm{W}_i \text{ x } \mathrm{WD}_i = \mathrm{W}_i \text{ x } \mathrm{WD}_i \text{ x } 1$$

$$e.g., \mathrm{VW}_i = 2.1 \text{ x } 0.5 \text{ x } 1 = 1.05$$

NOTE: Any dry bar segments have a total volume (VW_i) of 0 since they have a water depth (WD_i) of 0 in this equation.

$$\mathrm{VW}_i = \mathrm{W}_i \text{ x } 0 = 0$$

$$e.g., \mathrm{W}_4 = 3.6 \text{ x } 0 = 0$$

2. Calculate the volume of algae in each segment (VA_i) by multiplying the width of each segment (W_i) (*from calculation 2 above*) by the algae thickness in that segment ($\underline{\mathrm{AT}_i}$) and by the estimated percent bottom algae cover of that segment (AC_i). Alternatively, you can multiply wAC_i (*from calculation 3 above*) by the algae thickness in that segment (AT_i).

$$\mathrm{VA}_i = \mathrm{W}_i \text{ x } \frac{\mathrm{AC}_i}{100} \text{ x } \mathrm{AT}_i = \mathrm{wAC}_i \text{ x } \mathrm{AT}_i$$

$$e.g., \mathrm{VA}_1 = 2.1 \text{ x } \frac{25}{100} \text{ x } 0.2 = 0.525 \text{ x } 0.2 = 1.05$$

   Any segment that was a dry bar (DB_i) should be calculated with the volume of algae (VA_i) as 0.

$$e.g., \mathrm{VA}_4 = 3.6 \text{ x } \frac{0}{100} \text{ x } 0 = 0$$

3. Calculate the percent of the water column filled (PWCF) with algae by dividing the sum of the volumes of algae in each segment (VA_i) by the sum of the volumes of water in each segment (VW_i).

$$\mathrm{PWCF} = \frac{\sum(\mathrm{VA}_1, \mathrm{VA}_2, \mathrm{VA}_3, \ldots, \mathrm{VA}_i)}{\sum(\mathrm{VW}_1, \mathrm{VW}_2, \mathrm{VW}_3, \ldots, \mathrm{VW}_i)} \text{ x } 100$$

$$e.g., \mathrm{PWCF} = \frac{0.105 + 0.46 + 0.6 + 0 + 0.51 + 1.2 + 0.396 + 0.0665}{1.05 + 2.53 + 1.6 + 0 + 0.85 + 6.0 + 4.4 + 0.76} \text{ x } 100 = 19.4$$

Filamentous Algae Measurement Quality Assurance and Quality Control

Duplicate samples will be collected from 2.5% of the sites sampled and only when at least two people are on a sampling team. Both duplicates are collected at the same date and approximate time (as equipment sharing will allow) by different individuals. The duplicate data will be analyzed to ensure precision and repeatability of the sampling technique. Every effort is made to assure that all of the personnel who perform the filamentous algae measurements participate in duplicate sampling throughout the sampling season to ensure that all variability is being captured. The variances between individual techniques will be documented and used in future training sessions or individual re-training. ***See CHAPTER 14. Section A. Blanks and Duplicates starting on page 14-1 for additional information.***

Once a year, all field participants in the WAB attend mandatory training sessions in March-April prior to the initiation of the major sampling season. The purpose of these sessions is to ensure that all field personnel are familiar with sampling protocols and calibrated to sampling standards. Whilst a specific session on Filamentous Algae Monitoring is not covered, other sessions (*e.g.,* site documentation and completing the stream assessment forms, sonde calibration, water collection protocols, stream flow measurement, field blanks and duplicates, *etc*.) are covered. In the field, individuals who are more experienced in Filamentous Algae Monitoring will be teamed up to give hands-on training to less experienced to assure reinforcement of training and accurate results before they are allowed to maintain these stations solo. This document is also provided to all program personnel for review and use in the field.

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Attachment C

Sample Permit Conditions

A.001 DISCHARGE LIMITATIONS AND MONITORING REQUIREMENTS:

Permit Limits

During the period beginning 1/1/2020 and lasting through midnight /end_date/ the permittee is authorized to discharge from Outlet Number(s) 001 (Sanitary)

Such discharges shall be limited and monitored by the permittee as specified below:

Effluent Characteristic	Discharge Limitations							Monitoring Requirements	
	Quantity		Units	Other Units			Units	Measurement Frequency	Sample Type
00610 - (Ammonia Nitrogen) (Year Round) (ML-A) (RF-A)	21 Avg. Monthly	42 Max. Daily	Lbs/Day	N/A	1 Avg. Monthly	2 Max. Daily	mg/l	1/week	8 hr comp
00600 - (Nitrogen, Total (as N)) (Summer May 1-Oct 31) (ML-A) (RF-A)	Rpt Only Avg. Monthly	Rpt Only Max. Daily	Lbs/Day	N/A	Rpt Only Avg. Monthly	Rpt Only Max. Daily	mg/l	2/month	8 hr comp
00600 - (Nitrogen, Total (as N)) (Winter Nov 1-Apr 30) (ML-A) (RF-A)	Rpt Only Avg. Monthly	Rpt Only Max. Daily	Lbs/Day	N/A	Rpt Only Avg. Monthly	Rpt Only Max. Daily	mg/l	1/month	8 hr comp
00665 - (Phosphorus, Total) (Summer May 1-Oct 31) (ML-A) (RF-A)	Rpt Only Avg. Monthly	Rpt Only Max. Daily	Lbs/Day	N/A	0.5 Avg. Monthly	1 Max. Daily	mg/l	1/week	8 hr comp
00665 - (Phosphorus, Total) (Winter Nov 1-Apr 30) (ML-A) (RF-A)	Rpt Only Avg. Monthly	Rpt Only Max. Daily	Lbs/Day	N/A	Rpt Only Avg. Monthly	Rpt Only Max. Daily	mg/l	1/month	8 hr comp
50060 - (Chlorine, Total Residual) (Year Round) (ML-A) (RF-A)	N/A	N/A	N/A	N/A	0.009 Avg. Monthly	0.018 Max. Daily	mg/l	1/week	Grab
01119 - (Copper, Total Recoverable) (Year Round) (ML-A) (RF-D)	N/A	N/A	N/A	N/A	Rpt Only Avg. Monthly	Rpt Only Max. Daily	mg/l	1/year	8 hr comp
01114 - (Lead, Total Recoverable) (Year Round) (ML-A) (RF-D)	N/A	N/A	N/A	N/A	Rpt Only Avg. Monthly	Rpt Only Max. Daily	mg/l	1/year	8 hr comp

Samples taken in compliance with the monitoring requirements specified above shall be taken at the following location(s):
All effluent samples shall be collected at, or as near as possible to, the point of discharge. Effluent BOD5 samples shall be properly labeled and then reseeded, in accordance with approved procedures, prior to analysis.

This discharge shall comply with Appendix A - I MANAGEMENT CONDITIONS I - 12.

Attachment D

"Assessment of Filamentous Algae in the Greenbrier River and Other West Virginia Streams"

Assessment of Filamentous Algae in the Greenbrier River and Other West Virginia Streams

James Summers, WVDEP-DWWM

December 17, 2008

During the summer of 2007, WVDEP received numerous complaints regarding the amount of algae in the Greenbrier River. Most of the complaints centered on the Caldwell to Alderson section of the river; and at least one complaint was received about the level of algae further upstream in the Denmar area. Several employees of WVDEP were familiar with the problem and indicated that the algae bloom had been occurring at various intensities for decades; some asserted that the algae had been getting worse, and perhaps starting earlier, than it had historically.

In September 2007, a meeting within the WVDEP Division of Water and Waste Management was held to discuss the problem. Results of water quality samples from the Watershed Assessment Branch sample database (WAB-Base) were summarized at the meeting. The WAB-Base results showed elevated levels of phosphorus in Howard Creek. Howard Creek flows into the Greenbrier River at Caldwell where the algae problem was reported to begin. WAB-Base results also showed that phosphorus levels in Howard Creek were significantly higher below the White Sulphur Springs sewage treatment plant (WSS STP) than above the plant.

The WSS STP had a history of solids “washout” which resulted in sludge beds in Howard Creek. Seven golf courses and a fish hatchery are located on Howard Creek, upstream of the WSS STP. Additionally, significant cattle pasturing occurs in the Greenbrier basin upstream of Howard Creek, and the gradient of the river lessens somewhat near Caldwell. It was suggested that the soil particles from the upstream pastures that are high in phosphorus were settling out in this lower gradient section on the river, allowing some of the phosphorus bound to the soil to be released into the water column. Perhaps all these factors were combining to fuel a “perfect storm” of algae. There was no consensus in the September meeting on what the primary source of the algae problem was.

A TMDL effort for the Greenbrier river basin was already underway. All the field work for this TMDL had been completed, making available a large amount of recent water quality, biological, and pollutant source tracking data. During the 12 months of monitoring at 130 stations, the only violation of water quality standards was for fecal coliform bacteria. Nutrient samples were taken at several locations; there were no violations listed for nitrate, and currently there is no water quality standard for phosphorus in WV streams. Therefore, TMDLs were not required for nutrients. Pollutant source tracking efforts focused only on the fecal coliform impairments, not on nutrient sources. One outcome of the September meeting was to perform additional source tracking on Howard Creek and the Greenbrier River to better quantify the nutrient sources that could be contributing to the algae problem.

Nutrient Source Tracking

Observations of the location and intensity of the algae, both on the Greenbrier River and Howard Creek, were made; the accumulation and impact of sediment was evaluated in the “lower gradient” section of the Greenbrier River near Caldwell; historical river flow and rainfall data was assessed; a review of WAB-Base nutrient data was made; additional sampling included a storm event sampling on Howard Creek, a low flow “snap shot” of nutrient levels in Howard Creek, and a winter sampling event coordinated with DEP Environmental Enforcement inspection staff which included concurrent stream sampling and Compliance Sampling Inspections of the WSS STP and fish hatchery.

Photo 1. Greenbrier River at Hillsboro STP discharge where algae begins *(9-12-08).*

Photo 2. Greenbrier River 200-300 feet below the Hillsboro STP discharge *(10-17-07).*

Photo 3. Greenbrier River at mouth of Howard Creek *(9-25-07).*

Photo 4. Greenbrier River at above Fort Spring -between Ronceverte and Alderson *(8-29-08).*

Photo 5A. Different species of algae growing in cold water of Davis Spring *(8-25-08).*

Photo 5B. Vigorous periphyton growth on a rock taken from Tuscarora Creek near Martinsburg *(11-11-08).*

Photo 6. South Fork of South Branch Potomac River at Moorefield bridge *(8-17-08).*

Photo 7. Tygart Valley River near Elkins, above quarry *(9-25-08)*.

Photo 8. Cacapon River near Yellow Spring- below Wardensville *(9-25-08).*

Photo 9. *Hydrilla* beds on New River with some filamentous algae development. Near Glade Creek campground *(9-17-08).*

Photo 10. Filamentous algae along edge of New River just above Gauley Bridge *(9-17-08)*.

Photo 11. *Hydrilla* beds in the Caldwell pool of the Greenbrier River above Howard Creek *(9-25-07).*

River Flow and Rainfall

Archives from the USGS gaging station at Alderson and the National Weather Service were reviewed. While the summer precipitation and river flow have been below average for three of the last four years, the river flow was not exceptionally low - from an historical perspective (see Attachment 4).

Sediment Impact and Rooted Aquatic Vegetation

Sediment accumulates in the Greenbrier River in the long pool at Caldwell. This is one of the few places on the river where the typical rocky substrate of Greenbrier is completely coated with sediment. Moving from the top of the pool down, it was noted that as the sediment increased the amount of rooted aquatic vegetation (not algae) increased dramatically and eventually covered the entire river bottom (Photo 11). This type of rooted vegetation, genus *Hydrilla*, grows in large beds in several other rivers where sediment accumulated, most notably the New River. See Photo 9.

As a rule, wherever sediment accumulated in the Greenbrier River, the rooted vegetation thrived. This nutrient rich sediment most likely results from agricultural activities in the Greenbrier watershed. No biological impairments occurred in the Greenbrier basin during the pre-TMDL monitoring, indicating the gradient is high enough to move the sediment downstream with only minimal accumulation in the Greenbrier.

Algae Distribution

In the upstream section of the Greenbrier River in the Denmar area, there is a very clear starting point for the algae – immediately below the sewage treatment plant discharge for the town of Hillsboro (Photo 1 and 2). Hillsboro's discharge is about 20 times smaller than that from WSS STP or Ronceverte STP, so the algae bloom is relatively short lived. It begins waning just before the sewage discharge from the Denmar Correctional Center enters the river; there the algae bloom increases and continues down the river, again for only a relatively short distance, until it is gone.

Filamentous algae does not show up significantly in the Caldwell pool until Howard Creek, which drains the White Sulphur Springs area, enters the Greenbrier River. At this point filamentous algae clogs the *Hydrilla* beds and fills the water column (Photo 3). The algae gradually disperses across the river over the next half mile of riffles. Once the river reaches Ronceverte the algae is well dispersed. When the discharge from the Ronceverte sewage treatment plant enters the river, the algae again fills the water column along the side of the river into which the plant effluent is discharged.

Below Ronceverte the level of algal development continues to be significant through Fort Spring and Alderson (Photo 4). A slight temporary increase is found below the Alderson sewage treatment plant discharge, but the algae level is already high enough that the smaller discharge from Alderson doesn't have the dramatic increase that is seen below Howard Creek (White Sulphur Springs) and Ronceverte. Significant levels of algae continue through Pence Springs and begin tapering off by Talcott. A few sporadic small algae blooms were noted on down the river to its mouth (Attachment 1).

There is no algae bloom below the Durbin sewage treatment plant discharge to the Greenbrier River. An algae bloom was noted below Marlinton in mid-summer 2008, but disappeared by September. This is probably due to a varying calcium level in the river at this point. (The critical role of calcium will be explained later in this report.)

Away from the Greenbrier mainstem, the amount of filamentous algae found on Howard Creek itself was surprisingly low compared to the Greenbrier River. Rooted aquatic vegetation dominates the creek where sediment accumulates and periphyton thrives on the rocky substrate in other places. Even though there was less filamentous algae than originally expected (found later to be due to the calcium/hardness level) there were areas where filamentous algae accumulated in Howard Creek, and particularly of note were the areas upstream of the WSS STP discharge. Seven golf courses, a trout hatchery, and some minimal pasturing are located on Howard Creek upstream of the WSS STP.

Source Characterization

Fertilizer information was gathered from six of the seven golf courses. Nutrient content, application rates and dates, soil and water sample results, management practices, and other information was compiled and evaluated by WVDEP. (The seventh course is the farthest upstream and located on a section of Howard Creek where no filamentous algae was noted; fertilizer application rates from the other courses were used to estimate the loading from this course.) Research conducted jointly by Ohio State University and the USDA studied nutrient loss rates from golf courses; the phosphorus loss rate was 6.2% of the total applied, or 0.51 kg/ha/year (King *et al*, 2004). These USDA values were used to calculate the combined annual phosphorus loading contribution from the golf courses on Howard Creek. The combined phosphorus loss from the golf courses totaled 200-300 lbs/year, or about 3% of the total phosphorus loading in Howard Creek at its mouth.

During the pre-TMDL monitoring, WVDEP had taken monthly samples for one year on Howard Creek near its mouth, just below the WSS STP, just above the WSS STP, and upstream of six of the golf courses. This intensive sampling helped to segregate the WSS STP loading from other categories of sources (*Figure 1).* Grab samples of the stream taken during the low flow conditions of early fall of 2007 and a series of stream samples taken during a storm event both showed similar results (*Attachment 3*).

Figure 1. **Phosphorus Loading at Various Locations Along Howard Creek.** Stream loadings (lbs/day) are based on pre-TMDL sample results taken May through October 2004. The loading from the White Sulphur Springs STP was calculated from effluent sample results.

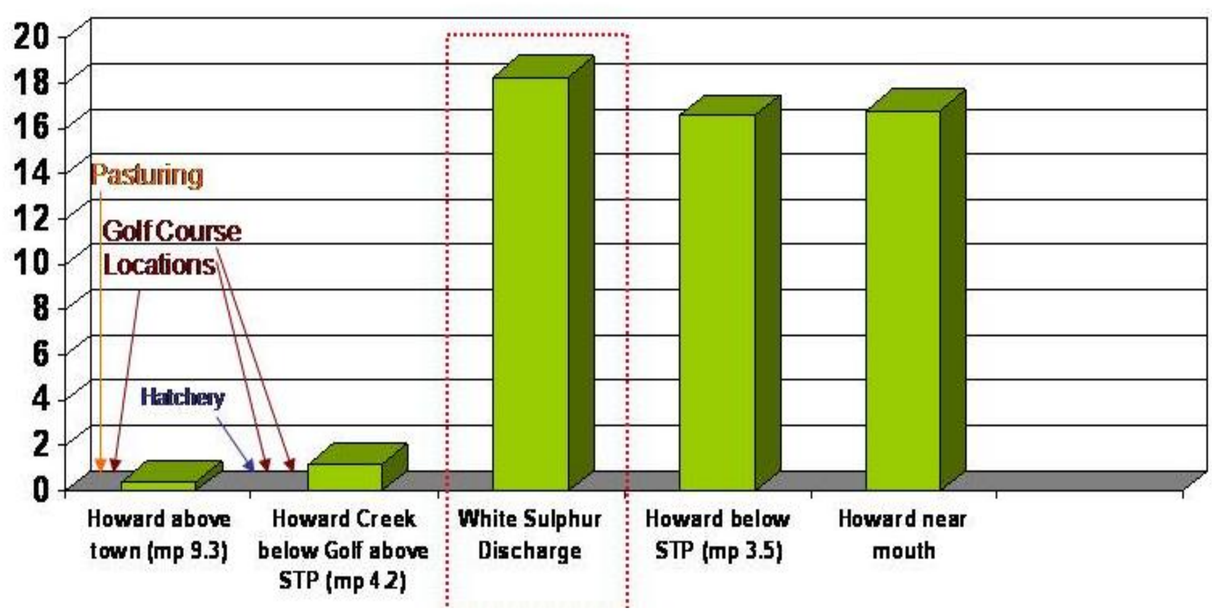
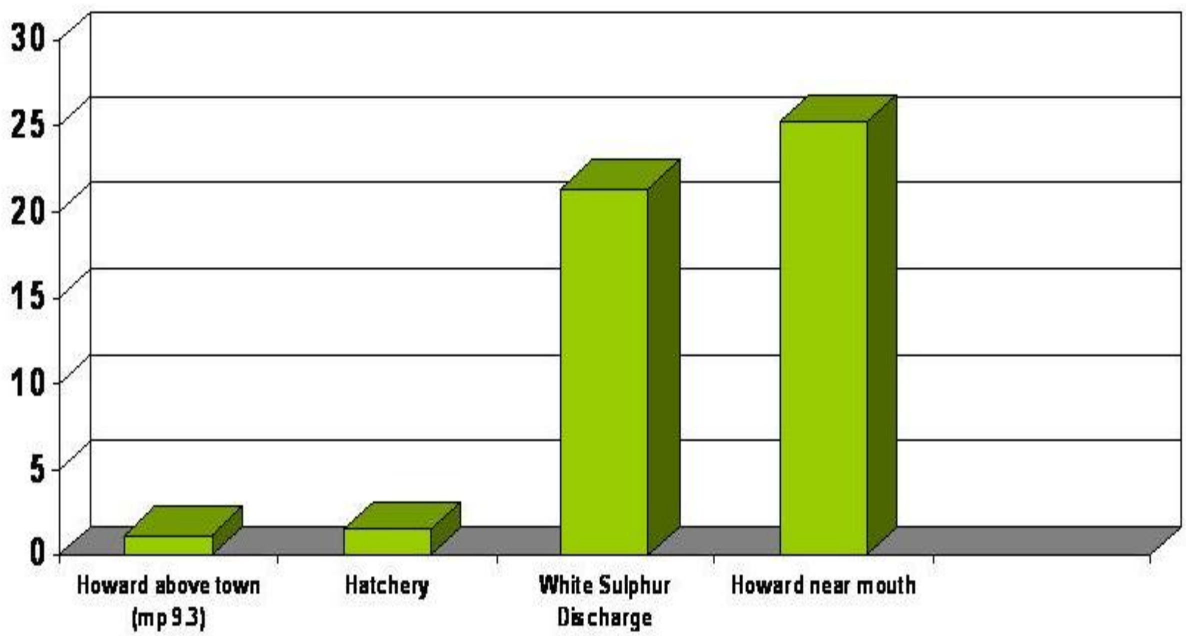


Figure 2. **Phosphorus Loading (lbs/day) During Compliance Sampling Inspections.**



Compliance Sampling Inspections were conducted concurrently at the WSS STP and the national fish hatchery; Howard Creek was sampled during the same time as the composite effluent samples were taken from the hatchery and WSS STTP. Again, the WSS STP accounted for most of the phosphorus loading in Howard Creek (*Figure 2).* Generally, the WSS STP accounted for 80-90% of the total phosphorus loading in Howard Creek throughout the year.

The conclusion drawn from the nutrient source tracking was that the algae in the Greenbrier River results primarily from the dissolved phosphorus in municipal sewage treatment plant effluent combining with nitrogen from a host of sources (agriculture, municipal discharges, and failing septic systems).

Keys to Algae Development

After the initial pollutant source tracking was performed, one question was obvious and had to be answered: If the algae bloom is driven by sewage treatment discharges, why is the algae bloom so severe on some portions of the Greenbrier River and not present on many other rivers in the state. A query of WAB-Base, which contains over 30,000 samples from across the state, turned up a clear difference in two important parameters – alkalinity and hardness. These two parameters, along with pH, serve as controlling variables and strongly influence the behavior of other constituents present in water (Weiner, pp 53).

Both alkalinity and hardness are indirect measures of multiple constituents, and are usually expressed as an equivalent concentration of $CaCO_3$. Hardness is a property of cations (Ca^{+2} and Mg^{+2}) while alkalinity is a property of anions (HCO_3^{-1} , CO_3^{-2} , PO_4^{-3}, and OH^{-1}).

Threshold Alkalinity

Significantly, no algae blooms were noted on streams where the alkalinity was less than 30 mg/l. Low alkalinity (less than 25 mg/l) keeps phosphorus from being available as a nutrient (Wurts, 1992) and could even limit algae growth due to low mineralized carbon levels. An alkalinity of greater than 50 mg/l is recommended for productive aquaculture ponds (Brunson, 1999). In West Virginia, low alkalinity rivers with municipal sewage treatment plant discharges include the Elk River, Cherry River, Little Kanawha River, and the upper Greenbrier River (Durbin area). Algae blooms have not been documented on these rivers.

Hardness Ceiling

Further, no significant algae blooms were present on several other rivers even though ample phosphorus, nitrogen, and alkalinity were present. When reviewing the WAB-Base data, it was noted that the hardness level on these streams tended higher than on the Greenbrier River (see *Table 4,* p 14). Hardness on the Greenbrier did not exceed 100 mg/l. The hardness on the West Fork River below the Weston STP discharge was 250-400 mg/l. Since hardness is a measure of Ca^{+2} and Mg^{+2} cations (sometimes iron and aluminum can mildly influence total hardness), a literature search was conducted to determine if there was any research on the role of calcium and magnesium in the development of algae in nutrient rich waters. There is a body of research on the topic, and it concludes that calcium and magnesium are key factors in algae development. Details are given in the "*Literature Review."*

Nutrients

A stoichiometric formula for algae has been estimated as $C_{106}H_{181}O_{45}N_{16}P$ (Craggs, 2005). One pound of phosphorous can then produce around 78 pounds of algae. (Some sources have reported this as 350 pounds, but this is incorrectly based on the molar ratios in algae, not the mass ratios). Nitrogen and phosphorus are incorporated into the algae cell structure at approximately a 16:1 nitrogen to phosphorus molar ratio (Redfield, 1958). But because nitrates leach from the soil more readily than phosphorus, nitrogen is generally much more available than phosphorous to aquatic vegetation. Consequently, algae growth in most surface waters will be limited by phosphorous (Weiner pp 98). Removing phosphorus is, chemically, the most efficient way to limit algae growth (Kennedy, 2004).

Under ideal summer growing conditions, algae blooms can occur with inorganic phosphorus concentrations as low as 0.005-0.01 mg/l (Weiner, pp 101; Kawaga, 1989). Weiner also notes that when phosphorous levels increase and cause algae growth to be limited by either carbon or nitrogen, long term mechanisms (CO_2 diffusion from atmosphere and changes in biological growth mechanisms) act to compensate for these deficiencies and algal growth once more becomes proportional to the phosphorous concentration (Weiner, pp 100).

In the Greenbrier River, algae blooms were occurring with P concentrations as low as 0.01-.014 mg/l. The amount of algae formation increased with an increase in P concentrations found below the discharges of the sewage treatment plants. (See graph in *Attachment 1*.)

This is not to say that phosphorus is more important than nitrogen in the growth of algae, only that growth tends to be limited by phosphorus in most cases. Nitrates are very soluble and come from a number of sources including pasturing, crop and lawn fertilizers, failing septic systems, and treated sewage discharges. Consequently, nitrates are rather ubiquitous in river systems. In the Greenbrier River, summer nitrate-nitrite concentrations run about half their winter level, despite the much higher winter time river flow which dilutes the phosphorus concentration. The summer N:P mass ratio in the Greenbrier River above Howard Creek is about 23:1. There is essentially enough nitrate loading in the Greenbrier at Ronceverte, 220 lbs/day, to fuel the algae growth for the combined phosphorus loading from both WSS STP and Ronceverte STP, even if the entire nitrate load from these sewage treatment plant discharges was removed. *Phosphorus seems to be the key to not only understanding the algae problem, but to alleviating it as well.*

Other Factors (Turbidity & Temperature)

Several other streams had a chemistry (alkalinity, hardness, phosphorus, and nitrogen concentrations) that seemed favorable for algae development, but no algae bloom had been reported. When these rivers were visited, many had significant algae development. These streams include portions of the Cacapon River, Bluestone River, New River, and Tygart Valley River. The North Fork of the Hughes River had some low to moderate algae development, but was somewhat suppressed given its chemistry; however, water turbidity was clearly a factor in limiting the algae development on the North Fork of Hughes. Other streams with favorable chemistry which did not have significant levels of filamentous algae had obvious limiting factors for algal growth, most often turbidity (Kanawha River and Brush Fork of Bluestone) or temperature (Piney Creek).

Given these observations, it seems likely that alkalinity and hardness, along with the known factors of nitrogen, phosphorus, and turbidity, play a key role in filamentous algae development in West Virginia's streams. It is reasoned that a minimum alkalinity is needed to make the phosphorous available for plant uptake, and that at higher hardness levels Ca/Mg precipitation with phosphorous occurs, making the phosphorus much less available for algae development.

Literature Review

Understanding the relationship between algae and phosphorus is complicated by the fact that an algae cell's ability to use specific forms of phosphorus is strongly influenced by several factors, including pH, hardness, the amount of dissolved oxygen, and temperature (Florida, 2000). Other environmental factors such as shading, grazing, turbidity, and substrate condition can maintain low algal biomass despite abundant nutrients (Dodds and Welch, 2000). Further, algae in streams and rivers occur in multiple forms, such as sestonic cells which are suspend in the water column, periphyton which grows on the substrate, and filamentous mats; these various forms may differ in their response to nutrient enrichment and the degree to which they are affected by other environmental factors (Royer, 2008).

The environmental behavior of phosphorous is largely governed by the generally low solubility of most of its inorganic compounds, and its strong adsorption to soil particles (Weiner, pp 97). Einsele and Mortimer demonstrated in the late 1930s and early 1940s that sediments retain phosphorous by fixation to iron. These results created a widespread opinion that phosphorous sedimentology was completely linked to iron chemistry, although it was known that calcareous sediments behaved differently (Bostrom *et al* , 1988). It has become evident in more recent research that phosphorus exchange between sediment and water is a highly complex phenomenon and includes many interrelated chemical, biological, and physical processes (Bostrom *et al* , 1988).

Orthophosphate, the mineralized form of phosphorus which is used by the algae, associates with particles by several types of bonding, from physical adsorption, to co-precipitation, to chemical bonds of different strengths (complex, covalent, and ionic bonds) (Bostrom *et al,* 1988). Supersaturation and/or undersaturation of phosphate salts may also occur, further complicating the study of the chemical processes which govern phosphorus availability (Diaz, 1994).

The role of calcium in phosphorus water chemistry has received far less attention than iron-phosphorus interactions (Bostrom *et al,* 1988). However, several researchers have investigated the connection of calcium to phosphorus uptake in algae. Magnesium ions, with the same plus two charge as calcium, behave similarly to calcium and are sometimes considered together with calcium in their combined impact on algae growth.

Bedore *et al* found that in the upper Illinois River, pH combined with Ca and Mg activity are the dominant chemical controls on phosphorus chemistry (2008). Vasata reported that the optimal concentrations of Ca and Mg for the productivity of algae decreased with increasing P concentration, and Kawaga *et al* found a regulating effect of dissolved Ca and Mg on the P-nutrition of algae, i.e. their Ca-Mg index could predict both the amount of suspended phytoplankton and the amount of phosphorus contained in the sestonic algae (1989). Masayoshi found a Ca/Mg ratio less than 4 had a negative effect on algal growth, and a Ca/Mg ratio greater than 5 enhanced growth (2000).

The effect of calcium and magnesium on phosphorus precipitation is variable depending on the chemical and physical conditions of the water system. Bedore found highly variable associations of phosphorus in sediment in streams impacted by municipal sewage treatment plant effluents. In five different sample locations, 20-70% of P was Fe-associated, 20-50% of P was bound in organic compounds, and 5-35% of P was associated with calcium minerals (2008). Bedore also noted that naturally hard water streams and rivers regularly experience high ionic strength, greatly complicating in-stream chemistry. Plant *et al* (2002) established that phosphorus co-precipitates with calcite in highly alkaline aquatic environments, although this may be inhibited as dissolved phosphorus levels approach 0.6 mg/l due to the cessation of calcite growth. Other reports have also suggested that phosphorus co-precipitates on calcite in hard water rivers (Avimelech 1980; Salinger 1993). Hartley suggested that Ca-P precipitation is a natural mechanism to control eutrophication in hard water lakes (1997). Long term P-accumulation in the Everglades was linearly correlated with Ca^{+2} accumulation (Reddy *et al* 1993).

That calcium and magnesium concentrations are strongly linked with algae growth is well established by research and observation. Generally, the Ca-Mg ions act to control the availability of phosphorus for algae uptake by the formation of relatively insoluble phosphate precipitates. The specifics of the phosphate precipitation are complex and can vary with the individual chemistry of each river system. Although the complexities of the mechanisms of Ca-P precipitation is not fully understood, the consensus is that the chemistry of the aqueous phase from which precipitation takes place is of paramount importance (Koutsoukos, 2000).

Phosphate Precipitation

Phosphorus based anions occur in several forms and are most often associated with calcium, magnesium, sodium, iron, and aluminum cations. All of the compounds have different solubilities, most of which vary significantly with pH, and formation of some P compounds will always be favored over others depending on the general chemical environment (alkalinity, hardness, conductivity, pH, redox potential, iron availability, etc.) in which formation occurs. *Table 1* shows the negative log of the solubility product constants (K_{sp}) for several simple phosphate compounds; while all (except sodium) are fairly insoluble, calcium phosphate is the *most* insoluble and is closely followed by magnesium phosphate.

Table 1. ***Solubility of Selected Phosphate Salts***

Compound	Formula	-log (Ksp) @25°C
Aluminium phosphate	$AlPO_4$	20
Calcium phosphate	$Ca_3(PO_4)_2$	27
Iron(III) phosphate dihydrate	$FePO_4 \cdot 2H_2O$	15
Magnesium phosphate	$Mg_3(PO_4)_2$	24
Sodium Phosphate	Na_3PO_4	Highly soluble

Table 2. ***Solubility of Calcium-Phosphate Minerals:*** From *Octacalcium Phosphate (Chow, 2001)*

Compound	Abbreviation	Formula	-log (K*sp*) @25°C
Monocalcium phosphate monohydrate	MCPM	$Ca(H_2PO4)_2 \cdot H_20$	Highly soluble
Monocalcium phosphate anhydrous	MCPA	$Ca(H_2PO4)_2$	Highly soluble
Dicalcium phosphate anhydrous	DCPA	CaHPO4	6.9
Dicalcium phosphate dihydrate	DCPD	$CaHPO4 \cdot 2H_20$	6.6
Calcite with co-precipitated P	CCP	$CaCO_3 \cdot PO_4$	8.47
alpha-Tricalcium phosphate	α-TCP	$Ca_3(PO4)_2$	25.5
beta-Tricalcium phosphate	β-TCP	$Ca_3(PO4)_2$	28.9
Tetra Calcium phosphate	TTCP	$Ca_4(PO4)_2O$	38
Octacalcium Phosphate	OCP	$Ca_8 H_2(PO4)_6 \cdot 5H_20$	46.9
Hydroxyapatite	HAP	$Ca_5OH(PO4)_3$	58.3
Fluorapatite	FAP	$Ca_5F(PO4)_3$	60.5

The Ca-P family of compounds may take on several different chemical forms (*Table 2*). Solubility product constants are experimentally determined, and there is some disagreement in scientific research and publication over the reported Ksp values for some of the Ca-P compounds. Perhaps the most important cause for inconsistent reporting is the metastability of some Ca-P salts in relation to other more stable forms (Moreno *et al*, 1966). (Metastable salts form an apparent equilibrium in solution, but change quickly to a more stable form with only a slight change of conditions. This further complicates the understanding of the specific chemical mechanisms of Ca-P precipitation.) There is, however, a generally accepted order of relative solubility.

$$\text{MCP} >> \text{DCP} > \text{TTCP} > \alpha\text{-TCP} > \beta\text{-TCP} >> \text{OCP} > \text{HAP}$$

Role of Magnesium

Hydroxyapatite (HAP) can account for up to 80% of phosphate precipitation, but the formation of HAP can be inhibited by the presence of magnesium ions (Cragg, 2005). Inhibition of HAP formation results in the formation of other Ca-P precipitates, mainly OCP and TCP (Diaz, 1994). Mg-P precipitates can also be produced. Magnesium forms similar chemical compositions as calcium with the phosphate ion: magnesium phosphate monobasic ($Mg(H_2PO_4)_2$) , dibasic ($MgHPO_4$), and tribasic ($Mg_3(PO_4)_2$). The solubility of magnesium salts is generally only slightly higher than that of calcium salts. All these compounds have low solubility products.

Diaz found the Ca-P equilibrium of stream water with various hardness levels could be controlled by OCP, β-TCP, HAP, or possibly a Ca-Mg-Fe-P complex. Which Ca-P mineral controlled the equilibrium depended on pH and Ca-Mg concentrations. It was suggested higher magnesium concentrations in harder water may be responsible for the formation of these less soluble Ca-P forms whenever dolomite (not calcite) is the thermodynamically dominant phase of carbonate. It has been reported that a Mg^{+2}/Ca^{+2} ratio greater than 0.6 indicates that dolomite is the thermodynamically stable phase, and calcite the dominant phase of waters where ratios are less than 0.6 (Hsu, 1963).

Literature Summary

1. Phosphorus is commonly the limiting factor for algae growth.
2. Ca and Mg play a key role in controlling instream phosphorus chemistry by forming numerous phosphate precipitates.
3. When phosphorous is in solid form, it is unavailable for algae to use.
4. Dolomitic streams are higher in magnesium content, and insoluble Mg-P precipitates can form in these waters.
5. Ca-Mg-P chemistry is very complex, and precipitate formation is dependent on stream-specific chemistry.

Application in West Virginia

Most streams in West Virginia can easily be classified as being dominated by either the calcite or dolomite by determining the Mg^{+2}/Ca^{+2} ratio during low flow summer conditions. Dolomitic streams include the Tug Fork, Coal, Guyandotte, and Mud rivers. Steams near equilibrium include the lower Elk, Birch, upper Kanawha, lower Gauley, Shenandoah, and New rivers. Strongly calcite streams include the Greenbrier, upper Gauley, upper Elk, Little Kanawha, Hughes, West Fork, Tygart, Cheat, Monongahela, South Branch Potomac, and Cacapon rivers. These lists show that streams from the southern coalfields region of the state are dolomitic streams. Magnesium is expected to play a dominant role in the phosphorus chemistry in these streams.

The Ca-Mg Index proposed by Kawaga was based on data for sestonic algae in lakes, but it also yields interesting results when applied to West Virginia rivers. Their index is proposed as the

$$\log[Ca^{+2}/Mg^{+2}] - 0.5 \log[Ca^{+2} + Mg^{+2}],$$

where Ca and Mg are expressed in molar concentrations, not mg/l.

Table 3 ranks the Ca-Mg Index for several WV rivers; those rivers with alkalinity below the threshold value for algae development (average 30 mg/l) are not shown in the table. The table shows an excellent correlation between the Ca-Mg Index and the level of algae development. It must be noted that the only factor removed from consideration here is low alkalinity; other factors, such as nutrient content and turbidity, also impact algae development and largely explain variations in the level of algae development in *Table 3*.

Table 3. **Ca-Mg Index for West Virginia Rivers**

River	Ca-Mg Index	Algae Development
Greenbrier River	2.15	Severe
Tygart Valley River	2.10	High
South Branch Potomac River	2.08	Low-Moderate
North Fork Hughes River	2.05	Low
South Fork/South Branch Potomac River	2.01	Moderate
Cacapon River	1.92	High
Bluestone River	1.81	Moderate-High
West Fork River	1.80	None
Monongahela River	1.77	None
New River	1.74	Moderate
North Branch Potomac River	1.71	None
Kanawha River	1.68	None
Guyandotte River	1.65	None
Shenandoah River	1.54	None
Tug Fork	1.50	None
Birch River	1.50	None
Coal River	1.25	None

Table 4. **Modified Ca-Mg Index for West Virginia Rivers**

River	Modified Ca-Mg Index	Avg. Hardness (mg/l)	Algae Development
Greenbrier River	3.26	65	Severe
North Fork Hughes River	3.24	63	Low [T]
Tygart Valley River	3.18	70	High
New River	3.1	79	Moderate [D]
Kanawha River	3.08	85	None [T]
Cacapon River	3.10	96	High
South Fork/South Branch Potomac River	2.95	112	Moderate
Bluestone River	2.94	121	Moderate-High
South Branch Potomac River	2.88	130	Low-Moderate
Guyandotte River	2.86	145	None
West Fork River	2.85	190	None
Monongahela River	2.84	149	None
Tug Fork	2.79	178	None
North Branch Potomac River	2.78	214	None
Shenandoah River	2.76	174	None
Birch River	2.74	221	None
Coal River	2.51	284	None
Mud River	2.49	373	None

T= Algae level reduced by turbidity. D= Algae level probably reduced by depth of pools in river.

For the sample results from WAB-Base used to calculate the Ca-Mg Index, the first half of the equation (*log[Ca^{+2}/Mg^{+2}]*)accounted for an average of 10.2% of the total Index score. The largest percentage impact was on streams with the lowest overall Ca-Mg concentrations, i.e. the Greenbrier and Tygart where it accounted for 15-20% of the Index score. A Modified Index, *-log[Ca^{+2} + Mg^{+2}],* was calculated and shown in *Table 4*. The results show a similar ranking of the rivers, and a good (perhaps even better) correlation between the modified index and the amount of filamentous algae development.

This Modified Index is a simple function of the Ca^{+2} and Mg^{+2} molar concentrations; *so is hardness*. It seems hardness could indeed be used as a basic indicator of a West Virginia stream's propensity to grow filamentous algae. A hardness level of less than 100 mg/l appears ideal for algae development. Suppression of algal growth seems to occur around 120-150 mg/l. And very little filamentous algal growth is seen when the hardness level is above 150 mg/l (except in AMD impacted streams where the low pH drives P-availability more than Ca and Mg do). Interestingly, this is a similar range to the hardness scale used for predicting soap performance, mineral deposits, and metals toxicity.

Table 5. **Hardness Scale** (Weiner, pp 77)

Degrees of Hardness	***mg CaCO3/L***	***Effects***
Soft	<75	No scale desposits Efficient use of soap Increase dissolution of metals.toxicity
Moderately Hard	75-120	Above 100 mg/l, significant scale deposits may form Requires more soap for cleaning Not objectionable for most purposes
Hard	120-200	Scale buildup and staining occurs Needs softened at ~180 mg/l
Very Hard	>200	Requires softening for household and commercial use

Hardness was originally used as a measure of the ability of water to precipitate soap and interfere with lathering. The interference occurs as a result of calcium ion replacing sodium ions in the soap molecules; the sodium carboxylates (like sodium phosphates) are very soluble, but the calcium carboxylates (like calcium and magnesium phosphates) are relatively insoluble when they form. This interferes with the surface tension created by the soap, reducing the lather. It is noteworthy that the negative log of Ksp values for the calcium carboxylates used in soap range from 7-19 (Bulatovic 2007); this is a similar, but slightly lower, range to the Ksp values of the expected and observed Ca/Mg-P precipitates which occur in hard water – indicating that the Ca/Mg-P precipitates would begin to form at somewhat lower concentrations. This is exactly what observations of algae development indicate.

This concept also lines up well with Diaz *et al*, who found that phosphorus solubility at calcium concentrations less than 50 mg/l (equating to 125 mg/l hardness) was not affected by pH in the range of pH 6-9. But where there was high calcium levels (>100mg/l) appreciable amounts of phosphate precipitated as the pH was raised from 6 to 9. Diaz points out that other researchers have found that P precipitation is minimal at Ca concentrations <50 mg/l and water pH <8.0 (Ferguson *et al* 1970, 1973; Jenkins *et al*, 1971; Otsuki and Wetzel, 1972; and Feenstra and de Bryun, 1979). Ferguson *et al* reported that a Ca concentration of 80 mg/l and a water pH >8, were needed to precipitate 80% of the P in municipal wastewater (1970, 1973). And Strang and Wareham (2006) reported significant P-removal through HAP precipitation in a sewage stabilization pond with a hardness of 190 mg/l and Ca of 60 mg/l.

Based on the observations, evidence, and research it seems that a sound explanation for the lack of algae in the many West Virginia streams with naturally hard water is the precipitation of calcium and/or magnesium phosphates, which makes the phosphate unavailable in the water column for uptake by filamentous algae. This is especially true of the dolomitic streams in the southern coalfields.

Other Factors

Turbidity/Substrate

Lower gradient streams with sediment laden substrate consistently have higher levels of turbidity, even during periods of low flow, due to recurring suspension of fine sediments (Royer, 2008). Such streams do not support algae growth since light penetration is drastically reduced by the turbidity. *Cladophora,* which is the dominant type of filamentous algae in the problematic areas in West Virginia, generally begins its growth attached to a rocky substrate or other hard surface (Harris, 2005). Parts of the North Fork of Hughes River, Little Kanawha River, Kanawha River, Brush Creek, Dunkard Creek, and others would fall into this category of streams with a turbid water column and silty substrate.

Secchi tube readings from the Hughes River show variation of the water clarity at different points along the stream. Clarity varied with bottom conditions in the river, and showed no longitudinal pattern. One thing was clear, though – filamentous algae grew in the least turbid areas of the river.

Table 6. **Role of Turbidity in Algae Development West Virginia Rivers**

River	Location	Secchi Tube Depth	Algae Development
North Fork of Hughes	North Bend	114	High
North Fork of Hughes	Cairo	84	Low
North Fork of Hughes	Below Cairo	76	None
North Fork of Hughes	Near Mouth	104	Low
South Fork Hughes	Smithville	103	None
Little Kanawha	Gilmer Station	114	None
Little Kanawha	Below Glenville	96	None
Kanawha	Charleston	108 (very good day)	None
Elk	Gassaway & Mink Shoals	>120	None
South Branch Potomac	Old Fields	>120	Low-moderate
Tygart Valley River	Above Norton	>120	High
Greenbrier	Ronceverte	>>120	High

Temperature

The temperature range for *Cladophora* growth is between 15-25^{o}C (Harris, 2005). No significant amounts of filamentous algae were found growing in any cold water streams (maximum temperature of 20^{o}C) in West Virginia, although another species of filamentous algae was growing in the Davis Spring (at Fort Spring) and Trout Run (near Franklin). It was noted that as the average temperature of the Greenbrier River at Alderson slipped below 20^{o}C this fall, algae began dying, and the diurnal pH and DO swings lessened – even as the flow in the river continued to decrease. See graphs in Attachment 2.

Table 7. **Average Summer Temperature for Selected Streams**

Stream	Average Temperature (°C) (May –October)	Maximum Temperature (°C)
Piney Creek (mp 0)	18.6	21.2
Indian Creek (mp 26.2)	18.6	20.1
Second Creek (mp 0)	18.5	23.3
Knapps Creek (mp 0)	18.3	21.6
Opequon Creek (mp 0)	18.0	21.9
Davis Spring	13.4	14.3
Greenbrier River	21.4	26.7

Temperature and/or shade are suspected to be the key suppression factors in Piney Creek, and a secondary factor in upper Indian Creek of New River and Second Creek of Greenbrier River. (Hardness was still the primary factor in Indian and Seconds creeks.)

Non-filamentous Algae

Other forms of algae may thrive in the nutrient rich waters of streams which have suppressed filamentous algae development. Tuscarora Creek, for example, is a tributary of Opequon Creek and receives flow from the Martinsburg STP. The average hardness of Tuscarora Creek is over 300 mg/l. With no filamentous algae development in this stream, it is expected that the phosphate is precipitating out of the water onto the bottom. Excessive periphyton development noted on the rocky substrate of Tuscarora Creek (see Photo 5B) seems to support of this conclusion. Similar colonies were noted in the mainstem of Opequon Creek and less vigorous development was observed in the Coal River. The interface of the rock, phosphate salts, and water would provide the most likely site for phosphorus release/exchange during equilibrium shifts. The periphyton development has not resulted in public outcry, and was not part of the scope of this investigation of filamentous algae development. No judgment is being made in this report as to whether the periphyton colonies constitute or contribute to any water quality problem.

Measuring Filamentous Algae

Schaller (2004) and Morgan (2006) employed similar methods for measuring filamentous algae in streams during their research. At a given stream transect, a tape is stretched across the stream; wetted width and portions of the stream covered by algae are recorded. At one location along the transect where the bottom is completely covered, all algae and plant material is collected in a 314 cm^2 area. The material collected is rinsed, dried, and weighed in a laboratory, and then expressed as mass per unit area. These researchers used that value to estimate mean biomass for the stream reach.

This method was used as a basis for algae measurement in West Virginia in the fall 2008. Measurements were made on several locations on the Greenbrier River, the North Fork of Hughes River, and at one location on the South Branch of Potomac River. The measurements were done as a trial to determine the feasibility of the method; no lab work was done determine a dry weight. An additional measurement was made of the algae depth across the transect, so that amount of water column impact, not just stream bottom, could be calculated. Results are summarized in *Table 8* and shown graphically in *Attachment 1*.

Table 8. **Algae accumulation at Selected Sites.**

River and Location	Bottom Cover (%)	Water Column Fill (%)
South Branch @ Old Fields	53	3.7
North Fork Hughes at North Bend	54	60
North Fork Hughes at Cairo	23	4
Greenbrier-Hillsboro 1	40	18
Greenbrier-Hillsboro 2	53	28
Greenbrier- Caldwell	53	32
Greenbrier –Coffman Hill Rd.	80	27
Greenbrier - near Rt 62 bridge 1	41	16
Greenbrier - near Rt 62 bridge 2	85	7
Greenbrier-Ronceverte	74	50
Greenbrier- US Alderson	64	23
Greenbrier- 1 mile below Alderson	39	10
Greenbrier-Lowell	46	9

WVDEP will continue work in the summer of 2009 to develop a measurement index which might be useful to define an acceptable level of algal development that still maintains unhindered recreational uses of the stream, including fishing, swimming, and aesthetic enjoyment.

Summary of Conclusions

1. Dissolved phosphorus discharged from sewage treatment facilities along the Greenbrier River is able to combine with nitrates in the river from a variety of sources and cause objectionable algae blooms.
2. Similar, but less severe, blooms are also occurring on the Bluestone, New, Cacapon, Tygart Valley, South Fork of the South Branch of the Potomac, and North Fork of Hughes River.
3. Lack of alkalinity keeps the algae blooms from occurring on several rivers: Elk, Cherry, Little Kanawha, and upper Greenbrier. A minimum alkalinity of 30-40 mg/l is needed for filamentous algae blooms to occur.
4. Hardness, in the form of calcium and magnesium, prevents algae blooms from occurring on several other rivers: West Fork, Tug, Shenandoah, Guyandotte, Mud, and Coal Rivers. The mechanism for suppressing the algae is the precipitation of Ca-P and Mg-P salts which makes the phosphorus unavailable for uptake by the filamentous algae.
5. Hardness levels exceeding 150 mg/l appear to inhibit algae growth. Some suppression of growth may begin occurring when hardness exceeds 100 mg/l. The South Branch of Potomac River appears to have suppressed filamentous algae development.
6. Hard water rivers with elevated phosphorus tend to have enhanced periphyton development on the substrate, probably due to its ability to utilize precipitated phosphorus at the substrate interface.
7. Algae blooms on some rivers, including the Kanawha River, are inhibited by turbidity.
8. Enhanced phosphorus removal at sewage treatment facilities along the Greenbrier River should substantially reduce the algae bloom occurring in that river.

References

Bedore, Paul D., Mark B. David (2008) *Mechanisms of phosphorus control in urban streams receiving sewage effluent. Water Air Soil Pollut.* 191:217-229.

Bostrom, B., J Andersen, S Fleischer, and M. Jansson (1988) *Exchange of phosphorus across the sediment-water interface. Hydrobolgia* 170:229-244.

Brunson, Martin W., Nathan Stone, and John Hargreaves (1999) *Fertilization of Fish Ponds*. Southern Regional Aquaculture Center, Publication No. 471.

Bulatovic, S. (2007) *Handbook of Floatation Reagents*. Elsevier Publishers, Amsterdam, pp 139.

Chow, L.C., and E. D. Eanes (2001) *Octacalcium Phosphate*. Karger Publishers, Basel, Switzerland, pp98.

Craggs, R. (2005) *Pond Treatment Technology*. IWA, London, pp 81-86.

Dodds, Walter K., Val H. Smith, and Kirk Lohman (2002) *Nitrogen and phosphorus relationships to benthic algal biomass in temperate streams. Can. J. Fish. Aquat. Sci*. 59:865-874

Dodds, Walter K. and Eugene B. Welch (2000) *Establishing nutrient criteria in streams. J. N. Am. Benthol. Soc*. 19(1):186-196.

Diaz, O.A., K.R. Reddy and P.A. Moore Jr. (1994) *Solubility of inorganic phosphorus in stream water as influenced by pH and calcium concentration. Wat. Res*. Vol. 28, pp 1755-1763.

Florida LAKEWATCH (2000) *A Beginners Guide to Water Management- The concept of limiting nutrients.* University of Florida Institute of Food and Agricultural Sciences. Circular 102. http://lakewatch.ifas.ufl.edu/LWcirc.html

Harris, Victoria (2005) *Nuisance algae on Lake Michigan shores.* University of Wisconsin Sea Grant Institute. Public information bulletin.

Kawaga, H. and M. Togashi (1989) *Contribution of dissolved calcium and magnesium to phytoplanktonic particulate phosphorus concentration at the heads of two river reservoirs. Hydrobiologia* 183:185-193

Kennedy, J. Todd (2004) *Use of Nitrogen to Phosphorus Ratios as Predictors of Nitrogen-Fixing Algae in Jordan Lake.* North Carolina Division of Water Quality.

King, K. W., J. C. Baloghb, K. L. Hughes and R. D. Harmeld (2006) *Nutrient Load Generated by Storm Event Runoff from a Golf Course Watershed.* USDA-ARS Surface Water Quality Technical Report.

Koutsoukos, Petros (2000) *Current knowledge of calcium phosphate chemistry and in particular solid surface-water interface interactions.* Institute of Chemical Engineering and Chemical Process. Univeristy of Patras, Greece.

Masayoshi, Mori and Kagawa Hisanor (2000) *Effects of calcium and magnesium on dissolved oxygen concentration on the Ishite River. Japanese Journal of Limnology* Vol. 61, No. 1, pp 11-20.

Moreno, Edgar C., Thomas Gregory, and Water E. Brown (1966) *Solubility of* $Ca \cdot HPO_4 . 2H_2O$ *and formation of Ion pairs in the system* $Ca(OH)$-H_3PO_4-$H_2 0$. *Journal of Research of the National Bureau of Standards-Physics and Chemistry*. Vol 70A, No 6: 545-552.

Morgan, Allyson M., Todd J. Royer, Mark B. David, Lowell Gentry (2006) *Relationships among nutrients, chloryphyll-a, and dissolved oxygen in agricultural streams in Illinois. J Envir. Qual.* 35:1110-1117

Plant, L.J. and W.A. House (2002) *Precipitation of calcite in the presence of inorganic phosphate.* Center for Ecology and Hydrology, Dorchester, UK.

Royer, Todd V., Mark B. David, Lowell E. Gentry, Corey A. Mitchell, Karen M. Starks, Thomas Heatherly II, and Matt R. Whiles (2008) *Assessment of chlorophyll-a as a criterion for establishing nutrient standards in the streams and rivers of Illinois. J. Environ. Qual* 37:437-447.

Schaller, Jamie L., Todd V. Royer, and Mark B. David (2004) *Denitrification associated with plants and sediments in an agricultural stream. J. N. Am. Benthol. Soc.*, 23(4):667-676.

Strang, T.J., D.G. Wareham (2006) *Phosphorus removal in a waste-stabilization pond containing limestone rock filters. J. Environ. Eng. Sci*. 5:447-457.

USGS Gaging Station 03183500, Greenbrier River at Alderson, WV. Real-time Website: http://waterdata.usgs.gov/nwis/uv?cb_00060=on&cb_00010=on&cb_00400=on&cb_00300=on&format=gif_default&period=36&site_no=03183500

USGS Gaging Station 03183500, Greenbrier River at Alderson, WV. Archives Website: http://waterdata.usgs.gov/nwis/monthly?referred_module=sw&site_no=03183500&por_03183500_1=1547792,00060,1,1895-08,2007-

Weiner, Eugene R., *Applications of Environmental Aquatic Chemistry- A Practical Guide, Second Edition* (2008) CRC Press, Taylor and Francis Group, New York. pp 53, 66-76, 96-104.

Wurts, William A. and Robert Durborow (1992) *Interaction of Carbon Dioxide, pH, Alkalinity, and Hardness in Fish Ponds.* Southern Regional Aquaculture Center, Publication No. 464.

Secondary Sources

Avnimelech, Y. (1980) *Calcium-carbonate-phosphate surface complex in calcerous systems*. *Nature*, 20:255-2557.
Cited by –Bedore (2008)

Feenstra, T.P., P.L. deBryn (1979) *Formation of calcium phosphates in moderately supersaturated solutions*. *J. Phys. Chem*. 83:475-479
Cited by Diaz (1994)

Ferguson, J.F., D. Jenkins, and J. Eastman (1973) *Calcium phosphate precipitation in slightly alkaline pH values. Journal of Water Pollution Control Federation*, 45:620-631
Cited by Diaz (1994)

Ferguson, J.F., D. Jenkins, and W, Stumm (1970) *Calcium phosphate precipitation in wastewater treatment. Chem. Engng. Symp. Serv*. 67:279-286.
Cited by Diaz (1994)

Hartley, A.M., W.A. House, M.E. Callow, and B.S.C. Leadbetter (1997) *Coprecipitation of phosphate with calcite in the presence of photosynthesizing green algae*. *Water Res*. 31:2261-2268.
Cited by–Strang (2006)

Hsu, K.J. (1963) *Solubility of dolomite and composition of Florida groundwaters*. *J. Hydrol*. 1: 288-310.
Cited by Diaz (1994)

Jenkins, D. J.F. Ferguson, A.B. Menar (1971) *Chemical processes for phosphate removal*. *Wat. Res.*, 5:369-389.
Cited by Diaz (1994)

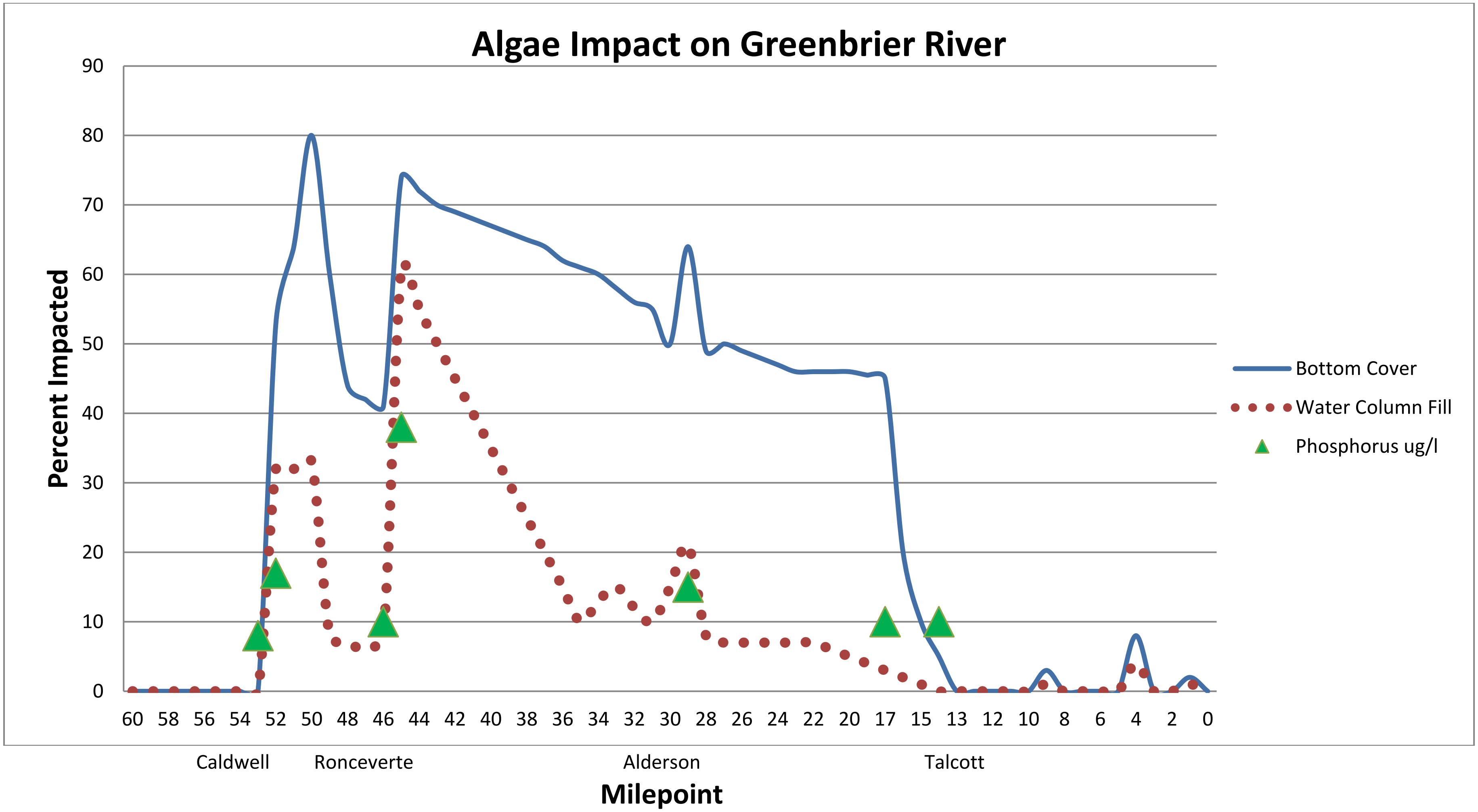
Otsuki, A. and R.G. Wetzel (1972) *Coprecipitation of phosphate with carbonates in a marl lake*. *Limnol. Oceanogr*. 17:763-767
Cited by Diaz (1994)

Redfield, A. (1958) *The Biological Control of Chemical Factors in the Environment*. *Am. Sci*. 45:205-221
Cited by –Kennedy (2004)

Reddy, K.R., R.D. DuLaune, W.F. DeBusk, M.S. Koch (1993*) Long-term nutrient accumulation rates in the the Everglades*. *Soil Sci. Soc. Am. J.* 57:1147-1155.
Cited by–Strang (2006)

Salinger, Y., Y. Geifman, M. Aronowich (1993), *Orthophosphate and calcium carbonate solubilities in the upper Jordan watershed basin. Journal of Environmental Quality*, 22:672-677.
Cited by –Bedore (2008)

Attachment 1



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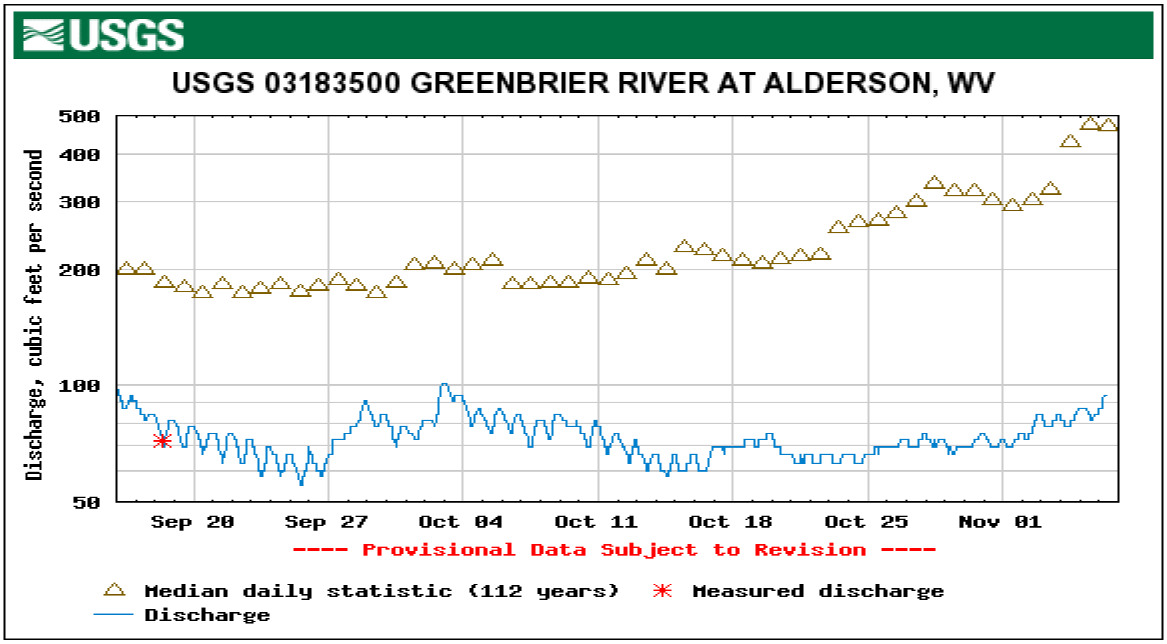

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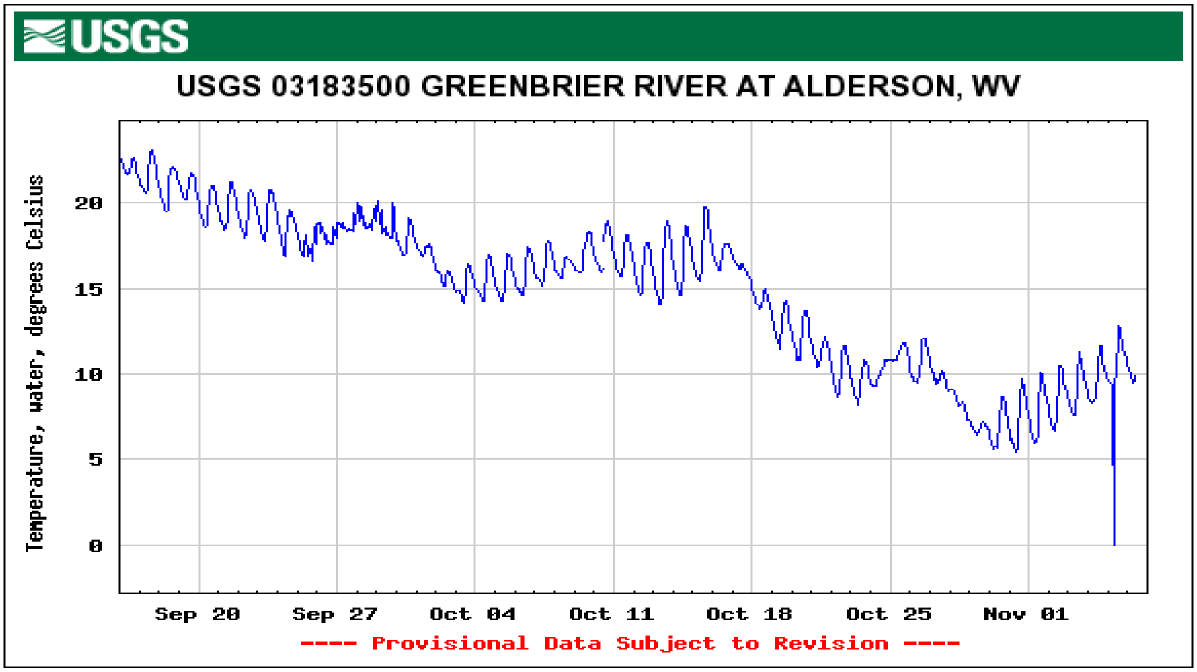

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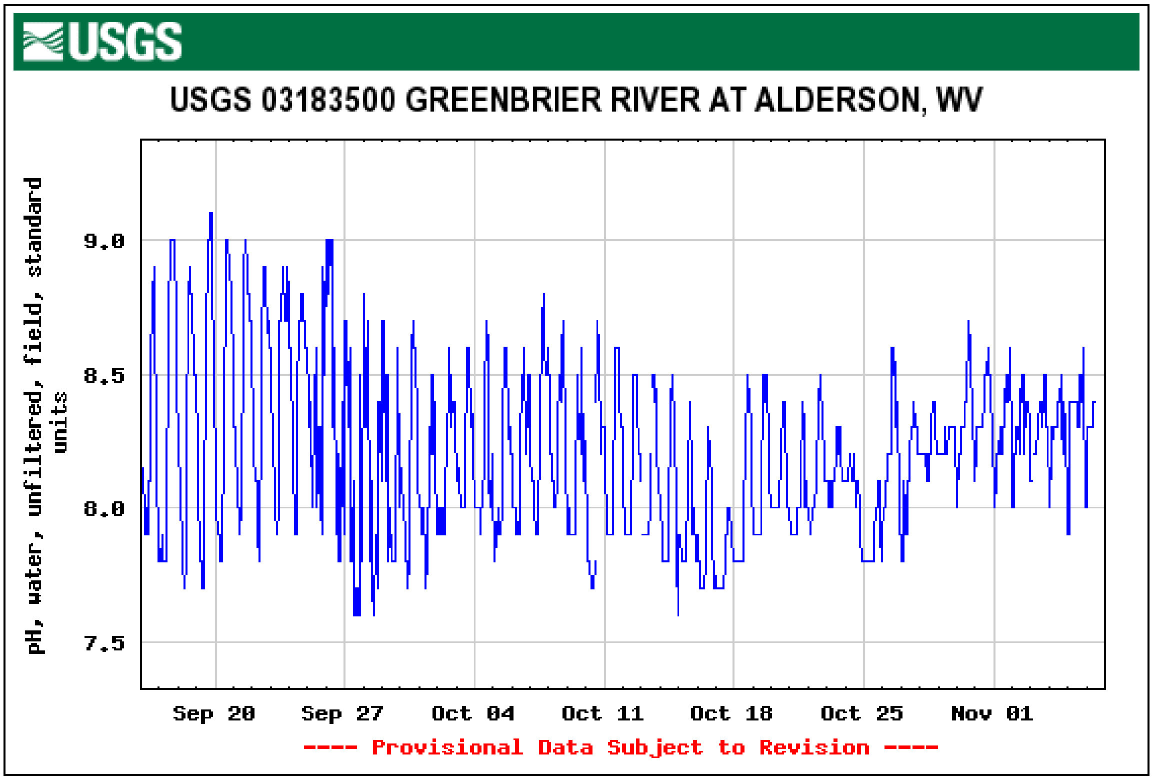

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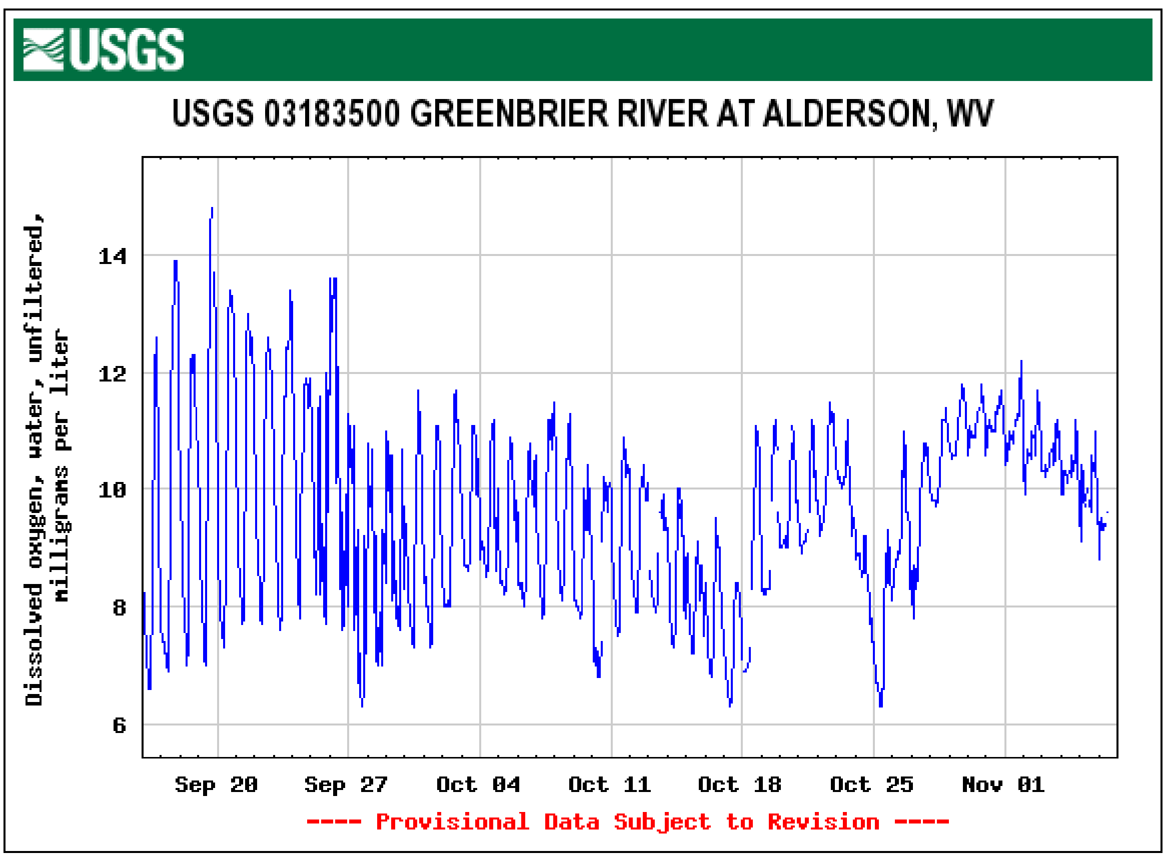
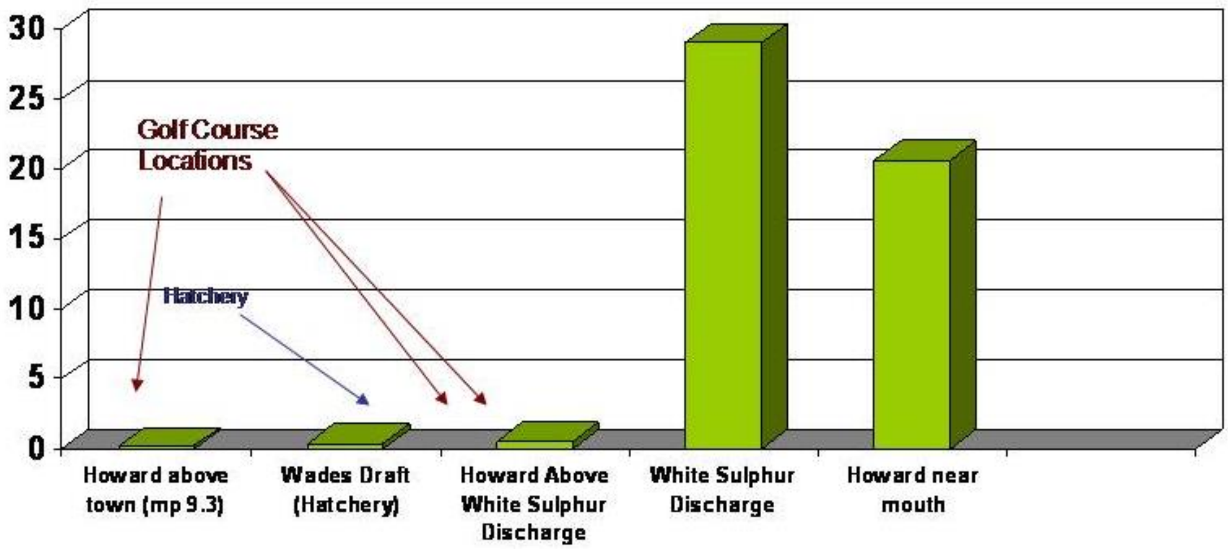


2008 Data

Attachment 3

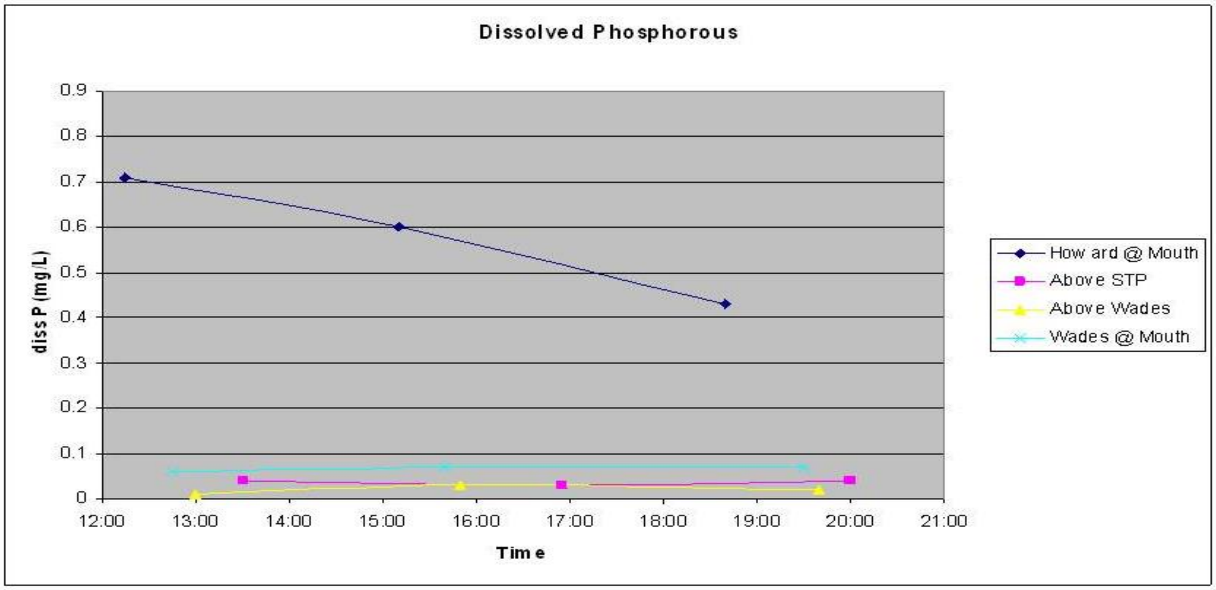
Dry Conditions Snapshot

Total Phosphorus Loading (lbs/day)



Storm Event

Phosphorus Concentrations (mg/l)
during a 2" rainfall event

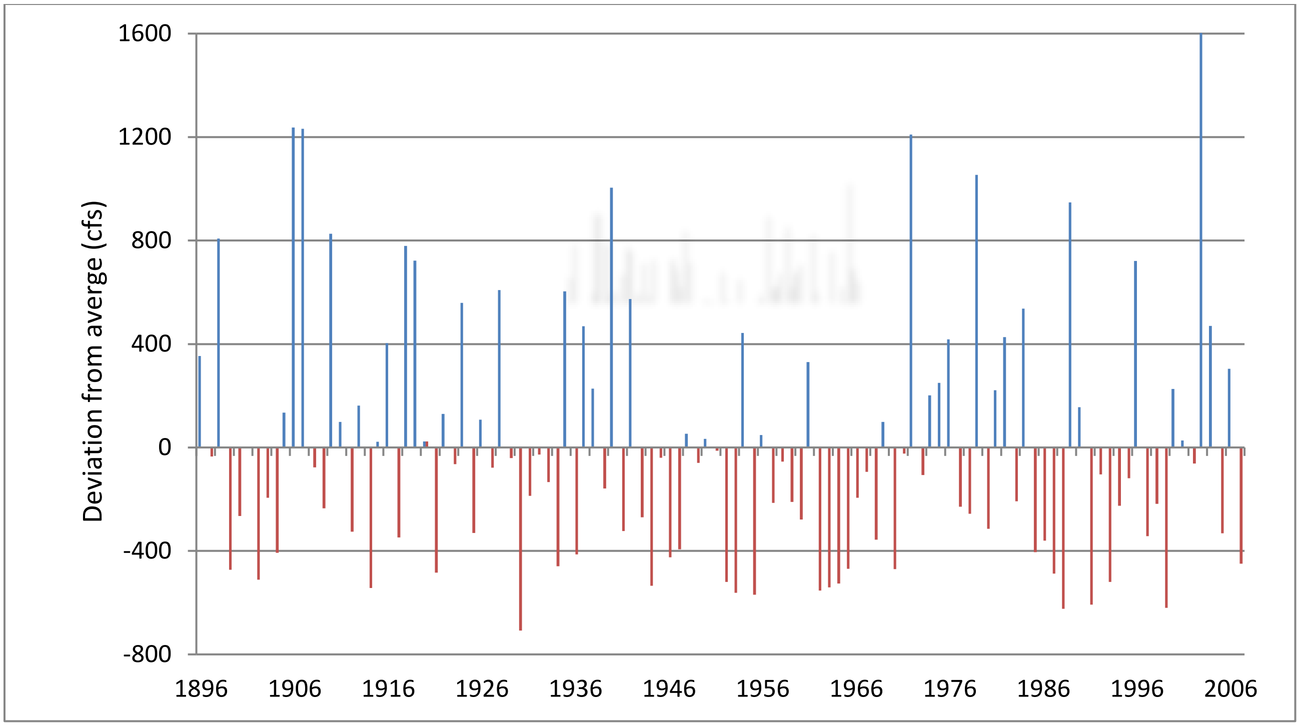


Attachment 4

Greenbrier River at Alderson

Deviation from the average summer flow, June through October, 1896-2007

(The average summer flow was 807 cfs)


1600
1200
800
400
0
-400
-800
Deviation from averge (cfs)
1896
1906
1916
1926
1936
1946
1956
1966
1976
1986
1996
2006

SDG

Attachment E

"Nutrient Levels and Filamentous Algae Growth"

Nutrient Levels and Filamentous Algae Growth
In the Greenbrier River:

A summary of 2009 Monitoring Data

James Summers, WVDEP-DWWM

June 21, 2010

In recent years, DEP has received numerous reports of excessive algal growth along certain sections of the Greenbrier River. These algae blooms have made fishing and swimming in the affected areas nearly impossible during the summer months. In order to address this loss of recreational use, DEP began evaluating algal growth on the Greenbrier River in 2007 to determine both the extent of impact and the sources of pollution which were contributing to these conditions. Both the chemical and physical conditions in the Greenbrier River – including hardness, alkalinity, temperature, clarity, and substrate – along with ample nutrient levels, proved to be ideal for growth of filamentous algae. Thick algal mats and/or large areas of attached filamentous algae growth occurred over approximately 50 miles of the river, at times stretching from bank to bank. Similar conditions occurred in 2008. During both 2007 and 2008, public water suppliers drawing river water from affected areas received numerous complaints of odor in their drinking water requiring initiation of additional treatment measures. The December 2008 report *Assessment of Filamentous Algae in the Greenbrier River and Other West Virginia Streams* summarizing the investigation is available on DEP's website.

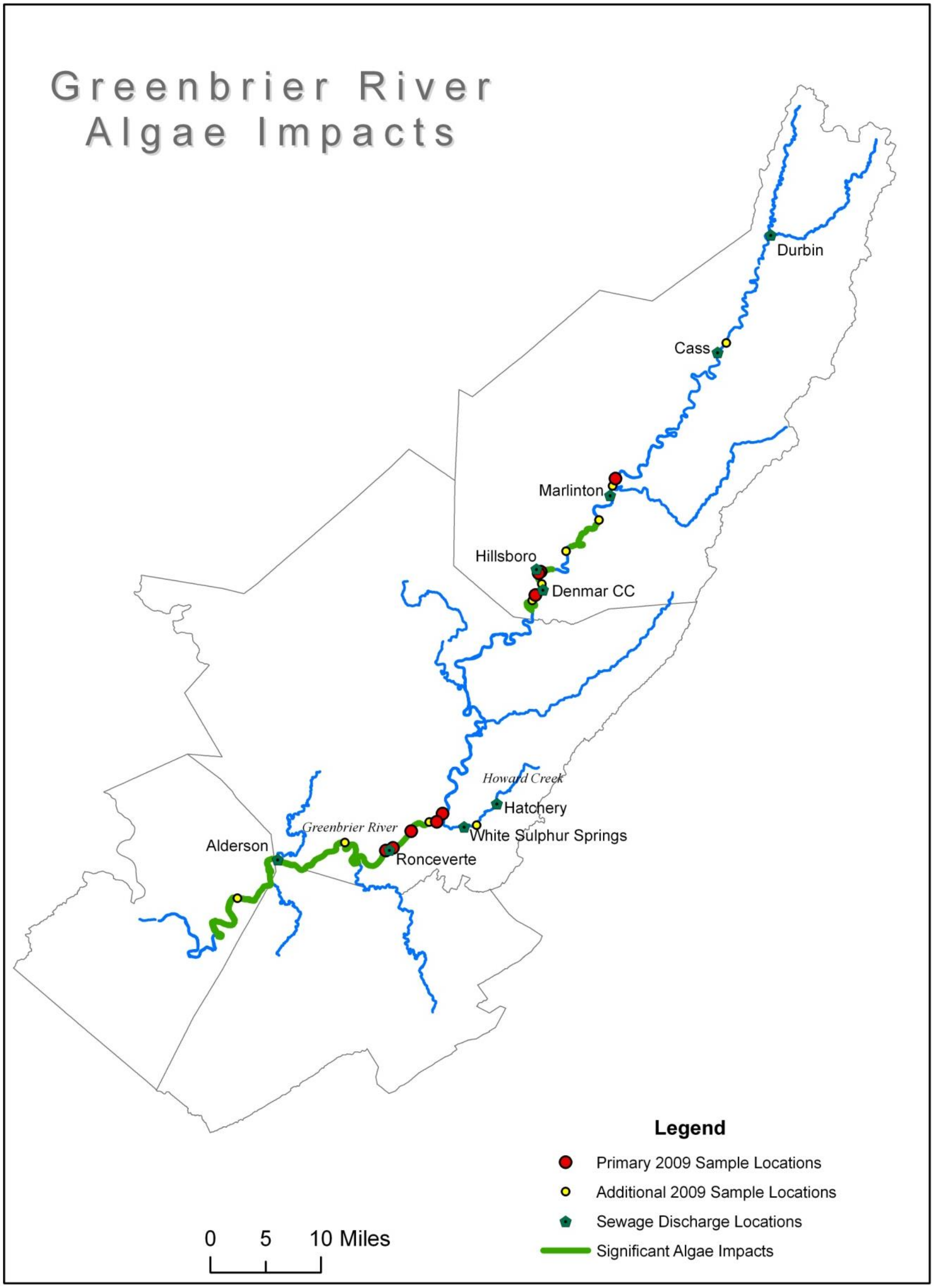
2009 Monitoring

In an effort to better understand what nutrient levels were occurring in the Greenbrier River, DEP personnel performed intensive water quality sampling along the Greenbrier River as the algae began to bloom in the summer of 2009. The overall purpose of this monitoring was to determine the nutrient concentration at which algae blooms began to occur and to verify whether phosphorus was the limiting nutrient. Nine primary sample stations were routinely monitored from late April through mid-September 2009 with a total of 14 rounds of sampling. These nine stations were generally located above and below permitted discharges from sewage treatment plants (see Figure 1 and Table 1). Additionally, seven other locations were monitored one or two times each to gather information to compliment the data generated at the nine primary sample locations. In-stream measurements were made of the temperature, pH, conductivity, and dissolved oxygen; lab analyses were conducted for total and dissolved phosphorus, TKN, nitrogen as nitrate-nitrite, alkalinity, hardness, calcium and magnesium. Previous sampling on the Greenbrier had utilized phosphorus analyses with detection limits of 0.01 and 0.02 mg/l, with many of the samples being at or below the MDL. The 2009 samples were analyzed using a MDL of 0.003 mg/l, which yielded much more insight into the actual phosphorus concentrations.

In-stream algae measurements were also performed at each sample event. Wetted width, portions of the stream covered by algae, depth of algae, length of algae filaments, and water depth were all recorded. Percent bottom cover and percent water column fill could then be calculated from these measurements.

A control site was set in the mixing zone of the Ronceverte STP, about 0.3 miles downstream of the discharge. Nutrient concentrations ran much higher in this mixing zone than at other sample stations on the river with well mixed sewage effluent. The algae began to grow in the Ronceverte mixing zone earlier than any of the other stations – about three weeks earlier than the station immediately upstream of the Ronceverte STP.

Figure 1.



Greenbrier River
Algae Impacts
Durbin
Cass
Marlinton
Hillsboro
Denmar CC
Howard Creek
Hatchery
White Sulphur Springs
Greenbrier River
Alderson
Ronceverte
Legend
Primary 2009 Sample Locations
Additional 2009 Sample Locations
Sewage Discharge Locations
Significant Algae Impacts
0 5 10 Miles

Table 1
2009 Sample Locations

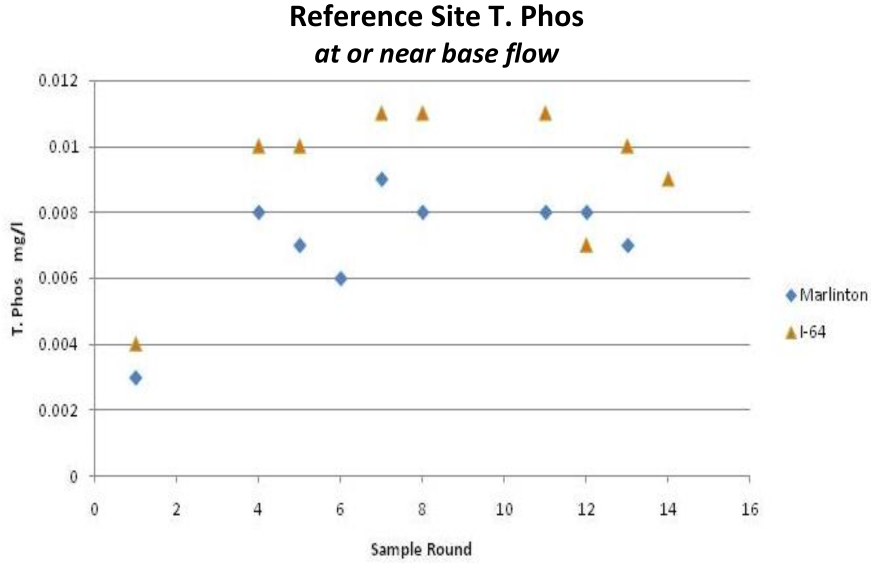
Sample ID	*Location Description*	*~River milepoint*	*Latitude/Longitude*
AGB-M00	Greenbrier River above Marlinton WWTP discharge. Left descending bank above Rt. 39 bridge.	114.3	38 13 30.6 80 05 42.7
AGB-BV	Greenbrier River below mouth of Beaver Creek. Midstream in riffle above the pool where algae bloom begins.	102.8	38 09 27.7 80 08 37.5
AGB-HB00	Greenbrier River above Hillsboro WWTP discharge. Right descending 0.2 miles upstream of discharge pipe.	96.6	38 06 23.9 80 13 04.2
AGB-HB2	Greenbrier River in Hillsboro mixing zone. Right descending bank ~50 yards downstream of discharge pipe in pool before any riffle.	96.4	38 06 17.5 80 13 20.1
AGB-D2	Greenbrier River below Denmar Correctional Center WWTP discharge. At old Beard ford. Stream location was middle-right.	93.5	38 04 26.2 80 13 48.9
AGB-64	Greenbrier River above Howard Creek (and White Sulphur Springs WWTP discharge). Right descending bank under I-64 bridge.	52.4	37 47 24.4 80 23 04.0
AGB-HC	Howard Creek upstream 0.2 miles from mouth. At Rt. 92 bridge, below White Sulphur Springs WWTP discharge.	(51.4)	37 46 41.9 80 23 40.4
AGB-HMZ	Greenbrier River in Howard Creek mixing zone. Middle left of river at top of riffle below Howard Creek (Caldwell) pool.	51.35	37 46 50.4 80 24 0.4
AGB-CH	Greenbrier River ~2.5 miles below Howard Creek at Coffman Hill Road Intersection. Left descending bank.	48.8	37 44 00.4 80 26 09.9
AGB-R00	Greenbrier River above Ronceverte WWTP discharge. Right descending bank above Rt. 219 bridge at city park.	46.8	37 44 41.0 80 27 58.6
AGB-R2	Greenbrier River in Ronceverte WWTP mixing zone. Left descending bank 0.3 miles downstream of discharge pipe.	46.1	37 44 27.2 80 28 42.8

Phosphorus Levels at Reference Sites

For the purpose of this report, reference sites means sample locations along the Greenbrier River where no algae blooms occurred at anytime during the year. These sites *did* have anthropogenic sources of nutrients located upstream, including small sewage treatment plant discharges and non-point source runoff from pasturing operations. The level of nutrients at the reference sites near Marlinton and Hillsboro (average: 0.007 mg/l TP & 0.005 mg/l Dis P) was somewhat lower than the nutrient level at the I-64 bridge upstream of Howard Creek (average: 0.009 mg/l TP & 0.006 mg/l Dis P). Dissolved-P generally ran from 0.005 to 0.006 mg/l at reference sites. Total-P results were more variable, with most running between 0.007 and 0.011 mg/l. The maximum Total Phosphorus recorded at any of the reference sites at base flow was 0.011 mg/l, and the 80-percentile value was 0.01 mg/l (See Table 2).

Although these sites did not exhibit any significant filamentous algae bloom, all the sites did develop what is termed as "background" levels of algal development – amounting to only minimal bottom cover with filaments less than one inch in length. The Hillsboro and I-64 sites had this background algae present for only one sample event and only on a few isolated rocks; the Marlinton site had the highest background level (2-3% bottom cover) and it persisted for only about two weeks.

Background Algae: *The highest level of algae growth at reference sites during the 2009 monitoring was 2-3% bottom cover, with filaments less than one inch in length. This photo is from above the Marlinton WWTP discharge in late June 2009 when to Total Phosphorus concentration was 0.006-0.009 mg/l, and illustrates the maximum level of background algae at any of the reference sites.*



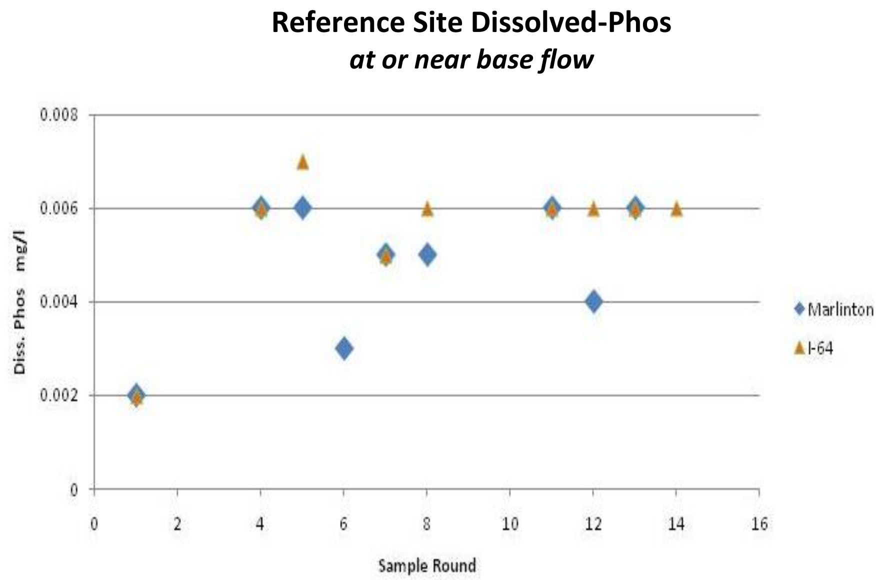
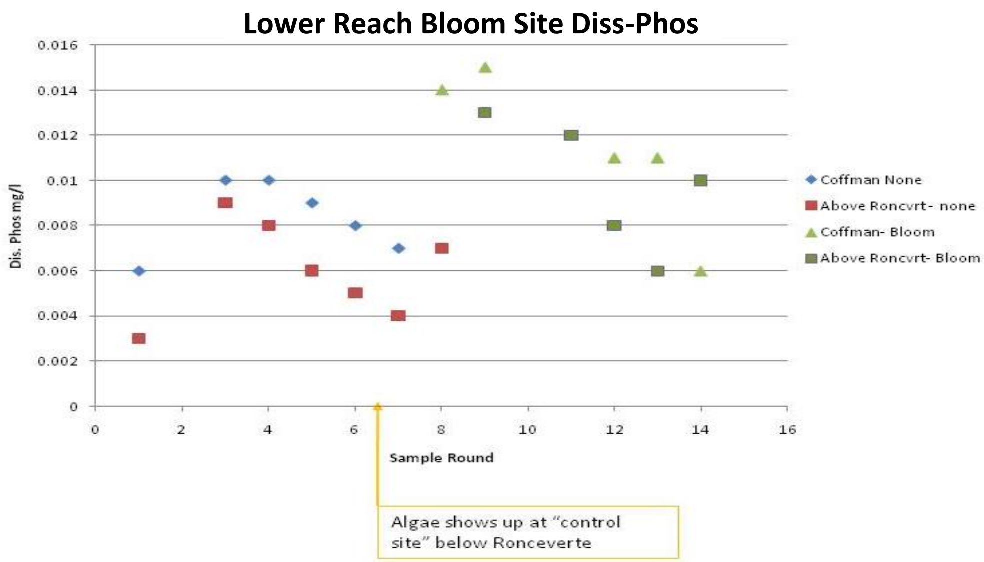


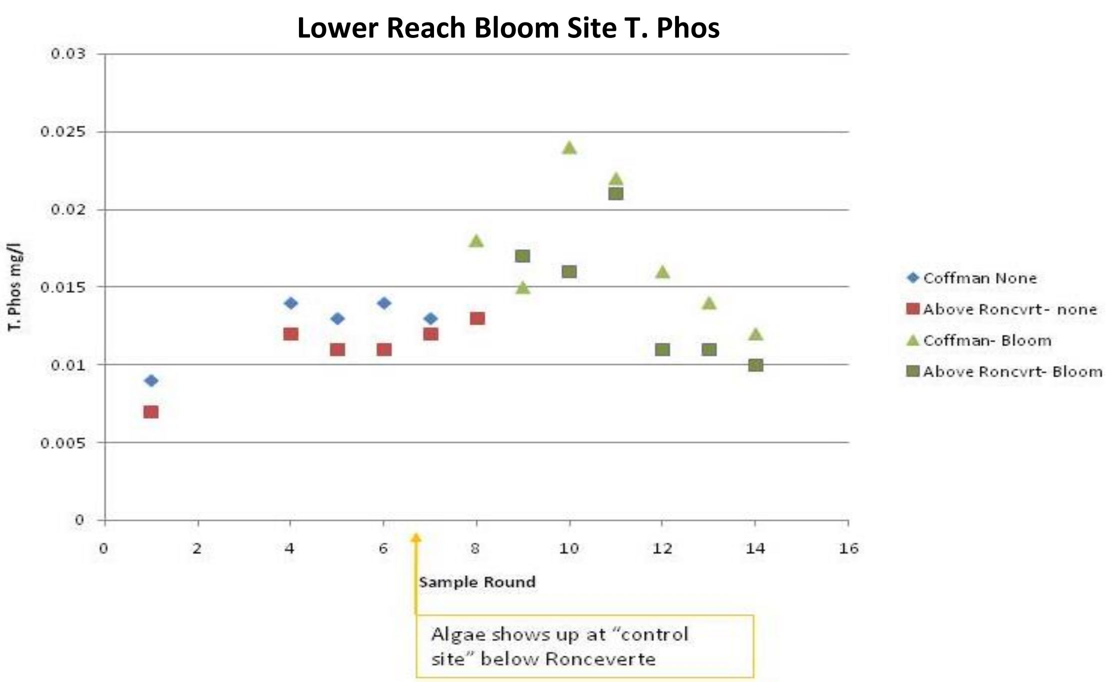
Table 2. **Total Phosphorus (mg/l) 2009 Greenbrier River**

Location Type	***Average***	***Std. Dev.***	***Min.***	***Max.***	***80-percentile***	***20-percentile***
Reference Sites	0.0082	0.0023	0.003	**0.011**	**0.010**	0.007
Bloom Sites (all samples)	0.0128	0.0041	0.003	0.024	0.016	0.010
Bloom Sites (growing season)	0.0148	0.0038	**0.010**	0.024	0.017	**0.012**

Phosphorus Levels at Algae Bloom Sites

Algae blooms had been correlated directly to sewage treatment plant discharges in 2007 and 2008. Sample sites located below STP discharges all developed algae bloom during the 2009 monitoring. While there was a fairly short period, 2-3 weeks, between the times when the control site (Ronceverte mixing zone) bloomed and when these other stretches of the Greenbrier began to bloom, there was enough difference that the bloom times could clearly differentiated. From the time that the control site bloomed until the other monitored sites began to bloom, there were also clear increases in dissolved phosphorus concentrations at the bloom sites. Since there was ample nitrogen available during the entire sample cycle, the concentration of phosphorus at which algae blooms occurred could be determined.





No algae blooms were occurring at the lower reach reference site (I-64) with total phosphorus concentrations running up to 0.011 mg/l. Dissolved phosphorus concentrations up to 0.007 mg/l did not support any algae blooms beyond background level (<3% bottom coverage). At lower reach sites where blooms did occur, total phosphorus concentrations from 0.012-0.014 mg/l could sustain a bloom.

At first glance of the Total Phosphorus graph on the previous page, it might be suspected that slightly higher concentrations of phosphorus (>0.015 mg/l) may be necessary for the bloom to begin. However, the dissolved phosphorus "controls" algae growth and that parameter trended down for several weeks prior to the bloom occurring. This is apparently why no bloom occurred, even though the total phosphorus values were 0.012-0.013 mg/l in the time period after the control site began to bloom.

Blooms did occur in the middle reach of the Greenbrier River as the total phosphorus concentration hovered between 0.011 and 0.015 mg/l, and with dissolved phosphorus concentrations between 0.007 and 0.009 mg/l. No blooms occurred anywhere on the Greenbrier River with a total phosphorus concentration less than 0.01 mg/l.

The hardness of the Greenbrier River generally increases from Marlinton downstream to below Alderson. When the phosphorus sample results are plotted against hardness, a correlation seems to be apparent. This provides a probable explanation for the somewhat softer water in the middle reach supporting algae blooms at slightly lower levels than the lower reach of the river. However, not enough information has been generated to determine whether a hardness-based water quality criterion for phosphorus would be appropriate. The 0.01 mg/l total phosphorus seems most appropriate for a single number to protect the *entire* Greenbrier River from excessive algae blooms.

Algae Bloom: *The level of algae growth below sewage treatment plants on the Greenbrier River has been significant each of the last several years. Bottom cover was nearly 100% in some locations with as much as 60% of the water column filled with algae filaments several feet in length. This photo is below the White Sulphur Springs WWTP discharge influence in early September 2009 when the Total Phosphorus concentration was 0.012-0.014 mg/l.*

Nitrogen

N:P ratios at the reference sites averaged 44:1 during the algae growing season, indicating that phosphorus is the limiting factor in algae growth at these sites. It was not until the introduction of the constant source of dissolved phosphorus from the sewage discharges along the Greenbrier River that algae began to bloom for miles below the discharges.

Samples taken for nitrate-nitrite above and below the influence of the White Sulphur Springs WWTP discharge at Howard Creek showed no significant change in nitrogen concentrations. The above and below sample concentrations in the river generally were within ±5%, sometimes higher upstream of the sewage discharge and sometimes higher downstream. However, during the latter part of the algae growth season (last two sample rounds in September) the nitrogen in the downstream sample where the algae was blooming was reduced by more than fifty percent. This is most likely due to the uptake of the nitrogen by the large amount of algae growing in the river.

Similarly, the N:P ratios also indicate that by the end of the growing season the algal uptake of nitrogen was significant. N:P ratios at bloom sites had dropped from an average of 30:1 during the growing season to <15:1 with the last two sample rounds, indicating that nitrogen had become the limiting factor in the growth of algae only at the end of the growing season after blooms were already well established over many miles of the river.

Sample results show that most nitrogen is coming from non-point source contributors, and that concentrations/loadings of the highly soluble nitrates increase significantly during high flow. Nitrate concentrations trend down as the weather becomes drier.

Summarizing, the growth of algae in the Greenbrier River was limited by phosphorus for 70-80% of the growing season. It was only late in the season after the blooms became well established over large sections of the river that nitrogen became a factor in limiting algae growth – providing a "ceiling" to the amount of bloom that could occur.

Proposed Numeric Criteria

Greenbrier River: Mouth to Beaver Creek (mile point 102.8)

Total phosphorus: 0.010 mg/l May-October @ base flow conditions

The EPA recommended TP criterion for rivers and streams in Nutrient Ecoregion XI, derived through statistical analysis of water sample results, is 0.01 mg/l. ***The EPA recommendation is the primary basis for value of the proposed phosphorus criterion.*** Other sources agree that a total phosphorus limit of around 0.01 mg/l may be necessary to prevent algae blooms from occurring in nutrient sensitive waters. There is general scientific agreement that the phosphorus concentration at which algae blooms can occur under ideal conditions is around 0.01 mg/l. The Greenbrier River does represent near ideal growth conditions for filamentous algae. Recent water quality sampling from the Greenbrier River at or near base flow conditions confirms that significant algae growth begins to occur in the middle reach as total phosphorus concentrations exceed 0.01 mg/l. Sampling also indicates that no blooms occurred with total phosphorus concentrations below 0.01 mg/l.

Proposed Narrative Criteria

Addition to "Conditions Not Allowable In State Waters"

3.2.g. "Algae blooms or concentrations of bacteria which may impair or interfere with the designated uses of the affected waters;"

DEP has taken a position that major algae blooms, as "distinctly visible floating or settleable solids", are a violation of 47CSR 2-3.2.a when the blooms are caused by point source discharges. However, this proposed clarification would remove any doubt whether or not discharges into state waters may cause significant algae blooms which interfere with the use of a stream. WVDEP will continue to evaluate whether an appropriate numeric standard for the amount of algae present in a flowing stream can be developed and implemented.

Summary

1. Algae blooms in the Greenbrier River are limited by phosphorus for most of the growing season.

2. No algae blooms occurred in the Greenbrier River with Total Phosphorus concentrations less than 0.01 mg/l.

3. Algae blooms did begin to occur and were sustained with total phosphorus concentrations over 0.011 mg/l.

4. Blooms occurred at slightly lower concentrations in the middle reach of the Greenbrier River (Marlinton to Denmar) compared to the lower reach (below Caldwell), probably due to a lower hardness (less calcium/magnesium activity) in this section of the river.

5. A Total Phosphorus criterion of 0.01 mg/l, as recommended by EPA for this ecoregion, is proposed as being suitable on the Greenbrier River from its mouth upstream to 102.8 miles to Beaver Creek to achieve significant reductions to the problematic algae blooms occurring on this section of river.

2009 Greenbrier River Sample Results

Location ID	Date	Temp	pH	DO	TSS	Alk	Hardness	T. Ca	T. Mg	NO2-NO3	Tot Phos	Dis Phos	%Bottom Cover
AGB-64	4/27/2009	19.47	7.69	7.7	<2	27	35.6	11.6	1.6	0.228	0.004	<0.003	0
AGB-64	5/27/2009	19.37	7.7	9.98	<2	36	46.9	15.3	2.1	0.237	0.019	0.009	0
AGB-64	6/2/2009	23.51	8.25		<2	35	49.8	16.3	2.2	0.17	0.01	0.006	0
AGB-64	6/9/2009	24.06	7.97	9.24	<2	34	51	16.3	2.5	0.15	0.01	0.007	0
AGB-64	6/15/2009	25.16	8.56	9.3	<2	40	53.2	17.5	2.3	0.19	0.009	0.007	0
AGB-64	6/24/2009	27.29	8.43	10.99	<2	51	65.3	21.7	2.7	0.272	0.011	0.005	0
AGB-64	6/29/2009	23.44	7.51	9	<2	55	72.7	24	3.1	0.213	0.011	0.013	0
AGB-64	7/9/2009	22.02	7.9	9.4	<2	58	76	25	3.3	0.265	0.012	0.01	0
AGB-64	7/12/2009	26.76	8.16	9.4	<2	58	78.2	25.7	3.4	0.226	0.015		0
AGB-64	7/22/2009	24.29	8.27	9.29	<2	60	75.8	24.6	3.5	0.17	0.011	0.006	0
AGB-64	8/12/2009	26.68	7.29	8.49	2	50	68.5	22	3.3	0.147	0.007	0.006	0
AGB-64	8/25/2009	27.03	8.47		<2	55	74.3	23.8	3.6	0.073	0.01	0.006	0
AGB-64	9/9/2009	26.24	8.92	12.98	<2	59	80.6	25.5	4.1	0.083	0.009	0.006	0
AGB-BC1	7/22/2009	23.06	8.68	8.23	<2	53	71.3	23.1	3.3	0.04	0.015	0.011	39
AGB-BC1	8/13/2009	26.58	8.15	8.13	<2	45	62	19.7	3.1	0.024	0.01	0.004	0
AGB-CASS	6/25/2009	20.57	7.83	10.88	<2	24	30.9	9.9	1.5	0.157	0.006		0
AGB-CH	4/27/2009	17.41	7.79	12.4	<2	27	1.9	12.3	1.9	0.234	0.009	0.006	0
AGB-CH	5/27/2009	19.14	7.97	10.27	5	39	50.6	16.3	2.4	0.236	0.024	0.01	0
AGB-CH	6/2/2009	21.64	8.77		3	37	53.4	17.1	2.6	0.159	0.014	0.01	0
AGB-CH	6/9/2009	22.02	8.62	10.55	<2	37	52.6	17.1	2.4	0.157	0.013	0.009	0
AGB-CH	6/15/2009	21.92	8.36	110	5	44	60.2	19.5	2.8	0.199	0.014	0.008	0
AGB-CH	6/24/2009	23.38	8.33	11.7	<2	56	71.6	23.4	3.2	0.281	0.013	0.007	0
AGB-CH	6/29/2009				<2	57	78.7	25.4	3.7	0.203	0.015	0.01	0
AGB-CH	7/9/2009	22.07	8.05	9.73	<2	58	83.8	26.8	4.1	0.233	0.015	0.015	2
AGB-CH	7/12/2009	25.89	8.97	11.22	<2	61	81.7	26.3	3.9	0.171	0.024		5
AGB-CH	7/22/2009	24.77	8.87	11.67	<2	65	89.2	28.3	4.5	0.132	0.022	0.012	12
AGB-CH	8/12/2009	25.25	8.65	9.68	<2	59	86.4	27.2	4.5	0.209	0.016	0.011	5
AGB-CH	8/25/2009	26.91	8.94		<2	38	82.4	25.9	4.3	0.03	0.014	0.011	12
AGB-CH	9/9/2009	23.47	9.11	14.78	2	65	82.1	25.3	4.6	0.038	0.012	0.006	25
AGB-D00	8/26/2009	25.11	8.24								0.01	0.05	5
AGB-D2	4/27/2009	19.05	8.32	11.77	<2	23	30.5	9.9	1.4	0.202	0.003	<0.003	0
AGB-D2	5/27/2009	18.08	7.77	9.87	<2	34	42.8	14	1.9	0.185	0.014	0.008	0
AGB-D2	6/2/2009	23.37	8.38		<2	29	41.8	13.6	1.9	0.109	0.01	0.008	0
AGB-D2	6/9/2009	23.59	8.27	9.45	<2	29	39.1	12.7	1.8	0.156	0.011	0.007	0
AGB-D2	6/9/2009	23.59	8.27	9.45	<2	29	39.9	13	1.8	0.147	0.01	0.007	0
AGB-D2	6/15/2009	24.75	8.24	10.47	<2	34	44.4	14.5	2	0.107	0.009	0.006	0
AGB-D2	6/24/2009	27.19	8.4	9.94	<2	40	52.4	17.2	2.3	0.108	0.015	0.004	<1
AGB-D2	6/28/2009	25.43	8.34	10.22	<2	45	61.3	20.1	2.7	0.077	0.011	0.007	20
AGB-D2	7/8/2009	27.38	8.75	13.61	<2	50	69.9	22.5	3.1	0.059	0.013	0.009	4
AGB-D2	7/13/2009	24.68	8.1	10.2	<2	54	71.7	23.6	3.1	0.093	0.016		15
AGB-D2	7/22/2009	23.67	8.31	8.99	2	52	72.5	23.6	3.3	0.048	0.014	0.015	20

Location ID	Date	Temp	pH	DO	TSS	Alk	Hardness	T. Ca	T. Mg	NO2-NO3	Tot Phos	Dis Phos	% Bottom Cover
AGB-D2	8/13/2009	23.22	8.04	8.34	<2	44	61.3	19.6	3	0.047	0.01	0.004	16.5
AGB-D2	8/26/2009	26.65	8.99		<2	47	63.8	20.6	3	0.048	0.012	0.006	50
AGB-FS	8/25/2009	23.73	8.22		<2	67	91.1	28.9	4.6	0.117	0.023	0.014	35
AGB-HB00	4/27/2009	19.1	8.1	11.1	<2	23	30.5	9.9	1.4	0.193	<.003	0.004	0
AGB-HB00	5/27/2009	17.84	7.86	10.15	4	34	44.7	14.6	2	0.185	0.013	0.007	0
AGB-HB00	6/2/2009	23.52	8.41		<2	30	41.8	13.6	1.9	0.11	0.009	0.006	0
AGB-HB00	6/9/2009	23.59	7.99	8.72	<2	28	39.1	12.7	1.8	0.127	0.008	0.006	0
AGB-HB00	6/15/2009	24.73	8.31	9.06	<2	34	44.9	14.7	2	0.101	0.007	0.005	0
AGB-HB00	6/24/2009	27.38	8.33	9.47	<2	40	51.5	17	2.2	0.104	0.014	0.007	0
AGB-HB00	6/28/2009	26.16	8.4	10.44	<2	44	61.6	20.2	2.7	0.077	0.007	0.006	0
AGB-HB00	7/8/2009	25.31	8.21	14.26	<2	48	69	22.7	3	0.086	0.011	0.009	0
AGB-HB00	7/22/2009	23.37	8.05	8.04	<2	53	73.9	24	3.4	0.05	0.013	0.006	<1
AGB-HB00	8/26/2009	25.21	8.19		<2	48	65.2	21	3.1	0.057	0.009	0.004	0
AGB-HB00	8/26/2009	25.21	8.19		<2	47	63.8	20.6	3	0.055	0.009	0.006	0
AGB-HB2	4/27/2009	19.11	8.04	11.17	<2	25	31.9	10.3	1.5	0.234	0.007	<.003	0
AGB-HB2	5/27/2009	17.74	7.9	10.1	4	35	45.2	14.8	2	0.225	0.016	0.009	0
AGB-HB2	6/2/2009	23.4	8.31		<2	31	42.2	13.6	2	0.144	0.011	0.006	0
AGB-HB2	6/9/2009	23.59	8.13	9.85	<2	31	41.5	13.5	1.9	0.192	0.012	0.007	0
AGB-HB2	6/15/2009	24.32	8.44	9.19	<2	36	49.4	16	2.3	0.183	0.009	0.007	0
AGB-HB2	6/24/2009	27.6	8.49	9.86	<2	42	55.1	18.1	2.4	0.172	0.008	0.005	0
AGB-HB2	6/28/2009				<2	46	64.5	21.2	2.8	0.137	0.01	0.007	0
AGB-HB2	7/8/2009	24.67	8.39	12.57	2	51	71.1	23.2	3.2	0.136	0.015	0.013	8
AGB-HB2	7/22/2009	23.47	8.09	8	<2	55	74.3	24	3.5	0.091	0.021	0.013	<3
AGB-HC	4/27/2009	18.62	8.82	11.8	3	40	65.3	19.6	4.5	0.215	0.043	0.047	0
AGB-HC	5/27/2009	18.47	8.29	11.43	<2	60	91.6	27.1	5.7	0.202	0.041	0.036	0
AGB-HC	6/2/2009	20.89	8.28		<2	45	75.5	22	5	0.24	0.051	0.043	0
AGB-HC	6/9/2009	23.33	8.66	9.87	3	55	95	28	6.1	0.225	0.054	0.048	0
AGB-HC	6/15/2009	22.16	8.42	10.64	<2	57	96.8	28.2	6.4	0.255	0.053	0.048	0
AGB-HC	6/24/2009	23.8	8.17	11.4	<2	64	99.3	29.2	6.4	0.344	0.061	0.057	0
AGB-HC	6/29/2009	21.77	8.32	11.6	<2	82	139	40.7	9.1	0.784	0.126	0.121	0
AGB-HC	7/9/2009	18.38	8.16	11.88	<2	68	121	35	8.1	0.429	0.077	0.076	0
AGB-HC	7/12/2009	23.96	8.6	10.5	2	79	135	39.5	8.9	0.434	0.114		0
AGB-HC	7/22/2009	21.3	8.63	10.97	<2	97	181	52.5	12.2	0.704	0.125	0.115	0
AGB-HC	8/12/2009	23.8	8.38	11.2	<2	102	190	54.5	13.2	0.525	0.093	0.089	0
AGB-HC	8/25/2009	25.77	8.66		<2	106	195	56	13.5	0.417	0.14	0.135	0
AGB-HC	9/9/2009	22.44	8.87	15.68	<2	117	214	61.8	14.6	0.985	0.303	0.295	0
AGB-HC00	8/25/2009	23.98	8.22							0.086	0.014		0
AGB-HCMZ	6/29/2009				<2	56	78	25.3	3.6	0.237	0.018	0.014	2
AGB-HCMZ	7/8/2009				<2	57	82.6	26	4.3	0.265	0.027	0.025	2
AGB-KC	8/26/2009	21.2	8.05	8.4	<2	62	101	31.6	5.4	0.898	0.008	0.005	0

Location ID	Date	Temp	pH	DO	TSS	Alk	Hardness	T. Ca	T. Mg	NO2-NO3	Tot Phos	Dis Phos	% Bottom Cover
AGB-MOO	4/27/2009	18.58	7.7	10	<2	17	23.4	7.3	1.2	0.194	0.003	<.003	0
AGB-MOO	5/27/2009	18.13	7.85	10.08	<2	27	33.6	11	1.5	0.14	0.012	0.007	0
AGB-MOO	6/2/2009	23.7	8.32		<2	24	33.8	10.9	1.6	0.106	0.008	0.006	0
AGB-MOO	6/9/2009	23.99	7.89	8.55	<2	22	30.4	9.7	1.5	0.109	0.007	0.006	0
AGB-MOO	6/15/2009	26	8.38	8.85	<2	28	37.9	12.2	1.8	0.075	0.006	0.003	0
AGB-MOO	6/15/2009	26	8.38	8.85	<2	29	37	12	1.7	0.073	0.006	0.004	0
AGB-MOO	6/24/2009	29.22	8.54	9.33	<2	34	41.1	13.5	1.8	0.093	0.007	0.003	3
AGB-MOO	6/24/2009	29.22	8.54	9.33	<2	33	40.9	13.4	1.8	0.089	0.012	0.005	3
AGB-MOO	6/28/2009	27.33	8.46	11.63	<2	36	48.6	16	2.1	0.071	0.008	0.005	3
AGB-MOO	7/8/2009	21.12	8.18	9.76	<2	44	57.2	18.6	2.6	0.147	0.009	0.005	0
AGB-MOO	7/13/2009	24.09	8.1	10.3	2	44	56.2	18.4	2.5	0.093	0.012		0
AGB-MOO	7/22/2009	21.67	8.24	7.87	<2	49	61	19.8	2.8	0.048	0.008	0.006	0
AGB-MOO	8/13/2009	24.77	7.83	7.94	<2	37	50.1	15.6	2.7	0.062	0.008	0.004	0
AGB-MOO	8/26/2009	23.12	8.06		<2	39	53.2	17	2.6	0.055	0.007	0.006	0
AGB-R00	4/27/2009	17.3	7.89	12.8	3	27	37.7	12.3	1.7	0.246	0.007	0.003	0
AGB-R00	5/27/2009	18.94	7.81	122	2	40	61.9	17	2.3	0.288	0.016	0.009	0
AGB-R00	6/2/2009	20.61	8.08		<2	38	52.4	17.2	2.3	0.193	0.012	0.008	0
AGB-R00	6/9/2009	21.92	8.15	9.69	9	35	48	15.6	2.2	0.16	0.011	0.006	0
AGB-R00	6/15/2009	23.08	8.91	10.55	2	45	61.6	20.2	2.7	0.218	0.011	0.005	0
AGB-R00	6/24/2009	25.03	8.39	11.05	<2	55	69.8	23	3	0.277	0.012	0.004	0
AGB-R00	6/29/2009	25.61	8.37	11.14	2	59	82.9	27.1	3.7	0.205	0.013	0.007	0
AGB-R00	6/29/2009	23.52	8.36	11.3	<2	59	81.7	26.8	3.6	0.217	0.014	0.008	0
AGB-R00	7/9/2009	23.56	7.98	9.97	<2	60	85.1	27.5	4	0.241	0.017	0.013	15
AGB-R00	7/12/2009	26	8.83	11.08	<2	64	85.8	27.6	4.1	0.161	0.016		10
AGB-R00	7/22/2009	24.89	8.64	9.62	<2	66	91.9	29.4	4.5	0.143	0.021	0.012	44
AGB-R00	8/12/2009	27.19	8.78	10.5	<2	54	77.9	24.6	4	0.143	0.011	0.008	3
AGB-R00	8/25/2009	26.78	8.4		<2	59	83.5	26.5	4.2	0.042	0.011	0.006	30
AGB-R00	9/9/2009	24.45	8.87	11.93	<2	61	77	23.6	4.4	0.034	0.01	0.01	40
AGB-R2	4/27/2009	16.77	7.74	11.65	<2	28	38.1	12.3	1.8	0.356	0.054	0.071	0
AGB-R2	5/27/2009	19.05	7.73	10.23	8	42	52.3	17	2.4	0.467	0.053	0.037	0
AGB-R2	6/2/2009	19.66	7.9		<2	40	57.2	18.3	2.8	0.499	0.08	0.067	0
AGB-R2	6/9/2009	21.19	7.73	9.69	2	36	52.1	16.9	2.4	0.409	0.076	0.068	0
AGB-R2	6/15/2009	21.75	8.05	9.2	4	47	67.1	21.6	3.2	0.744	0.123	0.106	0
AGB-R2	6/24/2009	23.63	7.85	10.22	<2	55	73.1	24	3.2	0.736	0.109	0.098	0
AGB-R2	6/29/2009				<2	58	81.7	26.6	3.7	1.29	0.231	0.221	10
AGB-R2	7/9/2009	22.62	7.91	9.92	<2	60	84.3	27	4.1	0.694	0.097	0.093	12
AGB-R2	7/12/2009				4	64	89	28.4	4.4	1.72	0.26		25
AGB-R2	7/22/2009	25.65	8.74	11.15	<2	64	92.7	29.2	4.8	2.31	0.496	0.477	47
AGB-R2	8/12/2009	25.81	8.41	9.15	<2	60	82.6	26	4.3	0.836	0.192	0.175	8
AGB-SEE	7/8/2009	23.69	8.42	12.68	<2	53	75.8	24.9	3.3	0.177	0.01	0.008	6
AGB-SEE	7/13/2009	23.4	8.01	9.8	<2	54	71.2	23.4	3.1	0.079	0.014		5