Appendix C:
West Virginia Upland Load Development

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C.1 West Virginia Model Loading Methods

The Upper North Branch Potomac River watershed includes areas in Maryland and West Virginia. A Mining Data Analysis System (MDAS) watershed model was developed for only the Maryland portion of the watershed. Loadings from the West Virginia portion were represented using time series boundaries and were directly added to the Upper North Branch Potomac River. The Stony River subwatersheds and *Group B* subwatersheds (Elk Run, Buffalo Creek, Abram Creek, Piney Swamp Run, and Montgomery Run) have existing metals total maximum daily loads (TMDLs) that were developed using MDAS (Figure C-1).[1]

The previous West Virginia MDAS models were updated with recent climatological data from 1999 through 2008. Flows and concentrations from the models were represented as discrete inputs/boundary conditions into the Upper North Branch Potomac River watershed model. The remainder of the West Virginia portion of the study area was represented using an index-watershed approach for baseline conditions. For future reduced conditions, the highest daily average concentration in the stream was reduced to the West Virginia criteria (1.5 mg/L). That percentage was then applied to the entire period for the subwatershed to determine future concentrations and loadings. Those loadings and the baseline loadings were in-stream loadings, as compared to the upstream/edge of stream loadings reported for Maryland subwatersheds. In-stream loadings were then converted to upstream loadings to be directly comparable to reported TMDLs for Maryland.

C.1.1 Index Watershed Approach

Twenty-one West Virginia subwatersheds were not included in the original West Virginia TMDL models. To include flow and loading contributions from the entire contributing area of West Virginia, continuous flow and iron concentrations from those tributaries were estimated.

First, variables that could help identify *similar* watersheds within the Upper North Branch Potomac River watershed were investigated. Watersheds were assumed to have comparable geomorphological features, land uses, and other elements that would exhibit similar hydrologic responses and potential sources and transport mechanisms for iron. Those variables were divided into the quantifiable variables as watershed area, circularity ratio, basin slope, and two land use classifications (forest and mining).

Watershed area, basin slope, and the circularity ratio are considered geomorphological components that represent hydrologic response, and they were selected on the basis of data availability. Watershed area represents runoff volume and peak flow rate to reflect hydrologic response and iron transport. Basin slope represents the influence on velocity from overland flow and channel flow to reflect hydraulics, iron transport, and possible iron-associated sediment transport. The circularity ratio represents the timing of peak discharge based on watershed shape to reflect runoff response and iron transport. Each land use category reflects different iron generation potentials.

Forest land use represents more than 60 percent of each watershed area and is the dominant land use. Iron loadings from forest tend to be small and can be episodic or constant. Relatively high metal loadings can occur during the snowmelt events, but, in general, loadings from forest are low when compared to other land uses and tend to dilute loads coming from altered lands.

[1] The TMDL documents discussing model development for these areas are at http://www.wvdep.org/Docs/3006_StonyRiver_TMDL.pdf (Accessed May 2009) and http://www.wvdep.org/Docs/12421_NBP_Final_TMDL_Report_2_13_07.pdf (Accessed May 2009)

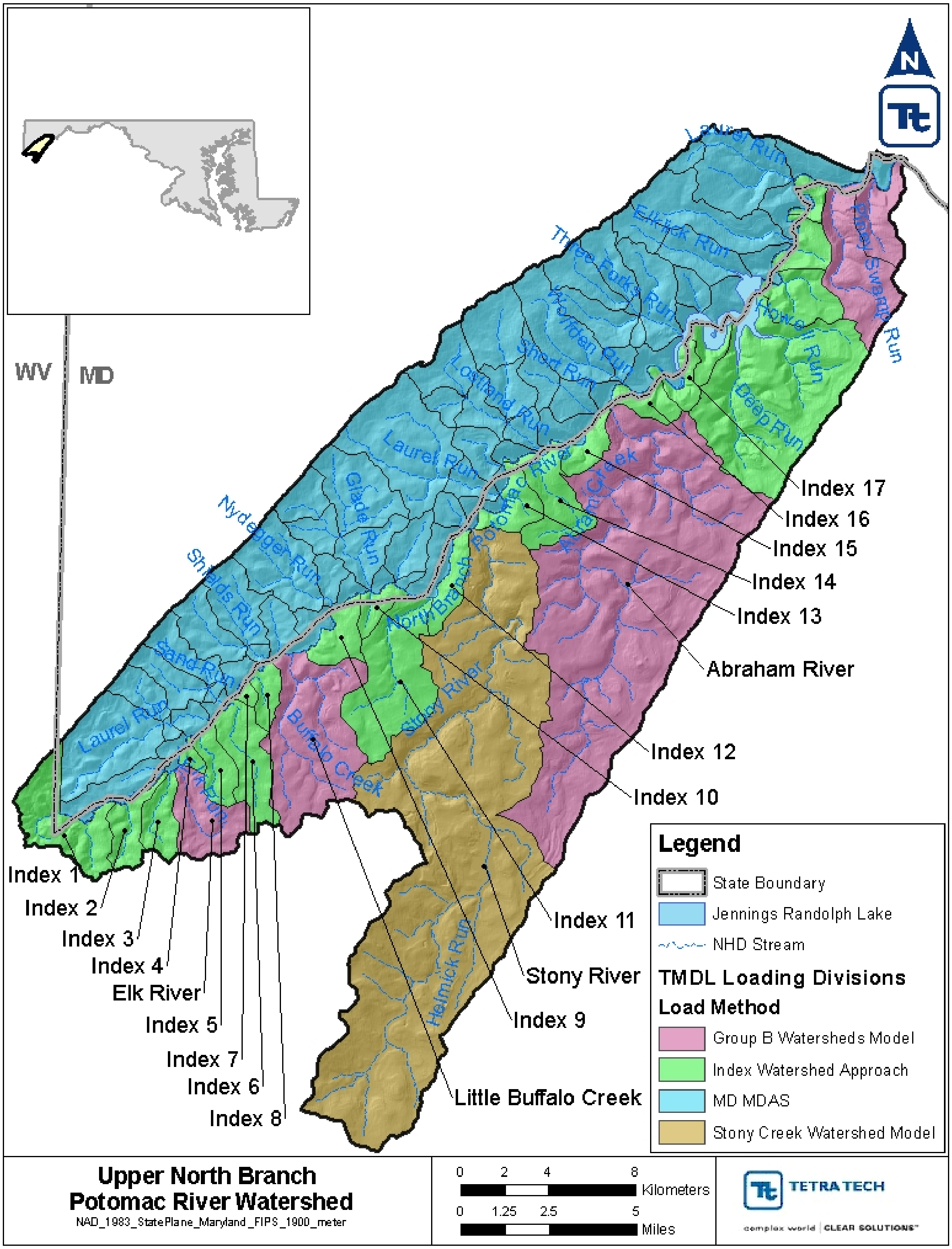

Figure C-1. Boundary condition areas for the UNBPR watershed MDAS model.

Therefore, because of the large contributing area, forest is included as a land use component of the modified cluster analysis.

Stream orders were identified for the previously modeled West Virginia watersheds, and several were selected as index watersheds. Watersheds containing large lakes were eliminated from the index watershed because flow attenuation and particulate detention mechanisms are different from the watersheds required to be estimated. For each potential index watershed, each previously described variable was transformed and standardized to eliminate unit differences among them.

The index-watershed approach uses a hierarchical cluster analysis with Euclidean distance to identify similar watershed characteristics and determine a weighted drainage area ratio to estimate loads for the watersheds with no loading data (non-index watershed).

In a hierarchical clustering analysis, watershed similarities are described by linkage distance shown on the Y-axis—the closer they are connected, the more similar they are. A distance matrix produced during the analysis helps to quantitatively evaluate the similarities or differences. Figure C-2 shows an example hierarchical cluster analysis result with the X-axis representing watershed IDs and the Y-axis showing the linkage distance. For example, according to the result, watersheds 1 and 16 are very similar and are clustered into the group also including 24. The plots and calculation were conducted using the statistics software STATISTICA.

After running the cluster analysis separately for geomorphologic and land use components, the linkages between non-index and index watersheds were transformed using z-scores ($z = \sigma\sqrt{x - \mu}$: σ = standard deviation, μ = mean). Z-scores provide a statistically based method for comparing the linkage results for the two components.

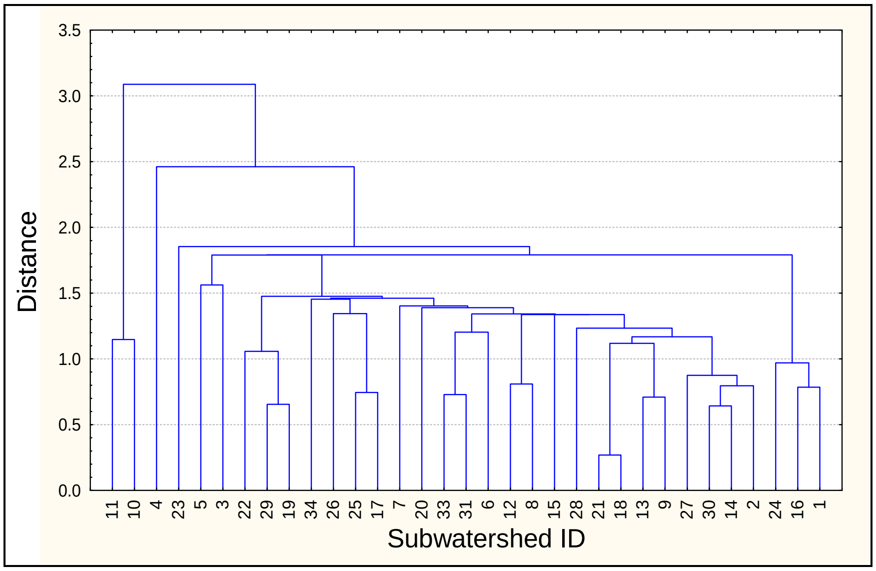

Figure C-2. Example result of hierarchical cluster analysis.

To select the most appropriate index watershed for a non-index watershed, greater weight was given to the geomorphologic scores, while still treating land use as an important factor of the hydrologic and iron generation/transport mechanisms. The first step in the comparison process was to sort the geomorphologic z-scores in ascending order. By doing so, the index watersheds were ordered from the smallest negative z-score to the largest positive z-score. The smallest negative geomorphologic z-score identifies the index watershed that is the most similar to the non-index watershed in terms of geomorphologic characteristics. Ideally, a watershed with the smallest geomorphologic z-score would also result in the smallest land use z-score, representing the shortest linkage of both components to the non-index watershed. However, often that is not the case. Therefore, to ensure that geomorphologic similarities are given priority, the top five index watersheds were selected from the ascending order on the basis of the geomorphologic z-scores. Then the geomorphologic and land use z-scores were summed for each five index-watershed, where the land use z-score is negative for that index watershed to ensure relatively similar land use. After evaluating the sum of the z-scores, the smallest summed z-score among the top five was selected as the index watershed for the non-index watershed.

After non-index watersheds were assigned with index watersheds, flow and concentration—needed to calculate the time series iron loading—were estimated from the assigned index watershed. Continuous flows were estimated by the weighted drainage area ratio between the index and the non-index watershed. The estimated iron loadings for the non-index watersheds were calculated by multiplying the area-weighted flow times the iron concentrations of the index watershed. The loadings were input into appropriate segments of the Upper North Branch Potomac River watershed modeling reach.

C.1.2 Conversion to Upstream Loads

The relationships among the travel time (reach length divided by velocity), upland loadings, and in-stream loadings from the MDAS model of the Upper North Branch Potomac River were used to estimate the upland loadings of West Virginia. Travel time was selected as one of the parameters because it is related to the deposition rate of particulate iron and can be estimated. The travel time for each reach within each subwatershed was derived by taking the average of MDAS velocities ouputs and the modeled stream distance estimated in the National Hydrography Dataset (NHD) for each subwatershed. Log transformation was applied to the data, and the data were input into software called *Total Accesses* to generate the linkages among the upland loadings, travel time, and in-stream loadings. The averages of the log transformations of those three parameters for each subwatershed in Maryland were used to conduct multiple regression analysis in an effort to link upland loadings to in-stream loadings. The R^2 values and derived coefficients for each parameter are listed in Table C-1.

Table C-1. Results from the multiple regression analysis

Y-Intercept	Coefficient for travel time	Coefficient for in-stream total iron load	R^2
0.81392	-0.07284	1.05252	0.75

The equation is expressed below and was used to estimate West Virginia's upland loadings.

$$\textit{upland loadings} = 1.05252 \times \textit{in-stream total iron load} - 0.07284 \times \textit{travel time} + 0.81392 \qquad (1)$$

Travel time in West Virginia was derived using Manning's equation. Bankfull depth and width for each subwatershed in West Virginia were derived by using Rosgen's cross-sectional stream coefficients for the exponential equations as shown in Table C-2. The selected coefficient values were the same values used for the Upper North Branch Potomac River MDAS model setup. Slopes for each stream were estimated by digital elevation map data and stream lengths from NHD data.

Table C-2. Bankful depth, width equation, and their coefficients

	a	b
$Bankfull\_Depth = a \times Contributing\_Area^b$	1.4995	0.2838
$Bankfull\_Width = a \times Contributing\_Area^b$	14.49	0.4

With the available data, flow was calculated using the bankfull depth and width. Flows and velocities at different depths—at 25, 50 , and 70 percent of the bankfull depth—were estimated with the same method for each subwatershed in West Virginia. Generated hydraulics data, flows, and travel time were used to generate an equation to derive travel time at different flow conditions for each subwatershed. Figure C-3 shows an example of the derived relationship between flow and travel time.

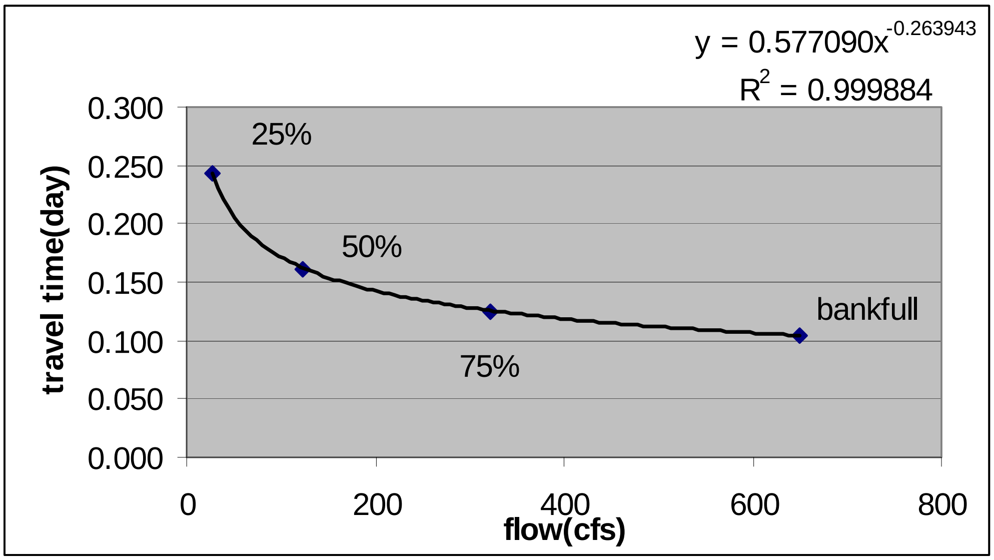

Figure C-3. The curve describing the relationship between flow and travel time.

Daily flows from West Virginia subwatersheds were input into the derived equation to estimate the travel time for the flow. Each West Virginia subwatershed has a unique flow and travel time equation that was used to estimate each travel time. The log-transformed, estimated travel time and available in-stream iron loadings results were input into the multiple regression equation (1) to generate daily upland loadings. The resulting log values were transformed back into upland loadings. The processes were repeated for all West Virginia subwatersheds to generate daily upland loadings and annual averaged loadings for baseline and future conditions.

C.2 West Virginia Modeling Results

Table C-3 presents the loadings from West Virginia. The first column lists the West Virginia segment. These segments correspond to Figure C-1. the next three columns are the loadings from the West Virginia TMDLs. TMDLs for Elk River, Little Buffalo Creek, and Abram Creek are represented as instream loadings at the base of the segment. The loadings for Stony River are the summation of instream loadings from all upstream segments. The last three columns represent the upstream edge of stream loadings form the Maryland model. These loadings were derived from model input, which was described in this appendix.

Table C-3. West Virginia Loadings

WV Segment	Existing WV TMDLs (lb/yr)			MD WV loads (lb/yr)		
	Baseline	TMDL	Load reduction (%)	Upstream baseline	Upstream allocation	Load reduction (%)
Index 1	--	--	--	64,196	64,196	0.0
Index 2	--	--	--	284,209	284,209	0.0
Index 3	--	--	--	32,325	25,418	21.4
Elk River	21,588	21,588	0.0	403,391	403,391	0.0
Index 4	--	--	--	9,665	9,665	0.0
Index 5	--	--	--	9,669	4,392	54.6
Index 6	--	--	--	77,704	26,904	65.4
Index 7	--	--	--	1,860	1,860	0.0
Index 8	--	--	--	176,056	176,056	0.0
Little Buffalo Creek	8,277	3,427	58.6	94,795	43,771	53.8
Index 9	--	--	--	35,145	27,635	21.4
Index 10	--	--	--	11,325	11,325	0.0
Index 11	--	--	--	169,930	58,724	65.4
Index 12	--	--	--	35,159	12,142	65.5
Stony River	328,391[a]	140,403[a]	57.2	269,239	269,239	0.0
Index 13	--	--	--	19,845	16,672	16.0
Index 14	--	--	--	16,484	15,994	3.0
Index 15	--	--	--	14,510	12,175	16.1
Abram Creek	68,925	31,395	54.5	401,087	347,260	13.4
Index 16	--	--	--	8,930	8,673	2.9
Index 17	--	--	--	11,072	11,072	0.0
Total	**427,181**	**196,813**	**53.9**	**2,146,595**	**1,830,771**	**14.7**