12-2006

Intermediate development of a forested headwater wetland HGM model for wetlands management in Virginia

Kirk J. Havens
Virginia Institute of Marine Science

David O'Brien
Virginia Institute of Marine Science

David Stanhope
Virginia Institute of Marine Science

Kory Angstadt
Virginia Institute of Marine Science

Daniel Schatt
Virginia Institute of Marine Science

See next page for additional authors

Recommended Citation
Havens, K. J., O'Brien, D., Stanhope, D., Angstadt, K., Schatt, D., Bilkovic, D. M., & Hershner, C. (2006) Intermediate development of a forested headwater wetland HGM model for wetlands management in Virginia. Virginia Institute of Marine Science, College of William and Mary. https://dx.doi.org/doi:10.25773/v5-2sk0-9v32

Authors
Kirk J. Havens, David O'Brien, David Stanhope, Kory Angstadt, Daniel Schatt, Donna M. Bilkovic, and Carl Hershner

Intermediate development of a forested headwater wetland HGM model for wetlands management in Virginia

Center for Coastal Resources Management
Virginia Institute of Marine Science
College of William & Mary

Final Report to
The U.S. Environmental Protection Agency
(CD # 973078-01)

December 2006

Intermediate development of a forested headwater wetland HGM model for wetlands management in Virginia

Kirk J. Havens, David O'Brien, David Stanhope, Kory Angstadt, Dan Schatt, Donna Marie Bilkovic, and Carl Hershner

Introduction

Wetlands associated with headwater areas are some of the least understood systems yet are acknowledged as some of the most important wetlands necessary to meet the Clean Water Act policy "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters"(Hupp 2000; Spingarn 2003). Headwater wetlands are located in the upper reaches of watersheds. These networks of streams and associated wetlands intercept and modify runoff and shallow groundwater entering streams that flow into the rivers and estuaries of the Commonwealth. It has been noted that these systems are analogous to capillaries in a blood circulatory system, acting as an interface between uplands and surface water networks similar to the relationship between organs and circulatory systems (EPA, 2003).

Headwater streams are directly influenced by the adjacent riparian zones and should not be considered apart from their associated riparian wetlands. They are considered particularly important for their potential role in water quality management. Most organic matter is introduced in waterways from upland sources in headwater areas. Organic matter is reduced in size by biological activity and travels downstream. Accordingly, headwater wetlands set the nutrient state of larger downstream systems and are the first step in treating water moving from uplands to streams. Peterson et al. (2001) suggest that small headwater streams can process more than 50% of inorganic nitrogen inputs from the contributing drainage area. Disturbance of headwater wetlands will affect water quality proportionately more than disturbance of wetlands further downstream (Peterjohn and Correll 1984, Cooper et al. 1987, and Brinson 1993). Headwater wetlands also serve important roles in moderating storm runoff and providing habitat. Headwater wetlands are areas that are presently under minimum regulation though studies have shown that wetlands associated with these systems are generally the most valuable in maintaining water quality.

Present federal regulation (33 CFR Section 330.2 (d)) and recent State regulation identify "headwaters" as surface waters with average annual flows less than 5 cubic feet per second (CFS) (equivalent to about a 3.2 million gallon per day flow). In federal regulation there is also a designation of Nationwide Permits for areas with average annual stream flows of less than 1 cubic foot per second (Federal Register 2000). In 2003, the EPA and the Army Corps of Engineers issued an Advanced Notice of Proposed Rulemaking (ANPRM) to "clarify" the scope of the federal Clean Water Act jurisdiction in regard to "isolated" wetlands, which under narrow interpretation could include headwater wetland systems (ANPRM, 2003). Determining an accurate average annual CFS flow requires extensive knowledge of landscape position, subsurface flow, soils, vegetation, precipitation, evapotranspiration, and elevation contours to name just a few variables. Current methods rely almost solely on crude area to flow relationships such as 1 square mile drainage equals 1 CFS flow (Federal Register 2000).

In a previous study (Havens et al. 2005), the NED and the Strahler stream order classification was used to determine the number of 1st order streams (used as a surrogate for 'headwater' streams) and their associated drainage areas. A GIS analysis of the National Hydrology Dataset (NHD) hydrology coverage for first order streams in the coastal plain of Virginia, using the Virginia Base Mapping Program at 10m resolution to develop drainage areas, suggests the number of headwater drainage areas less than 4 square miles may total over 18,000 with over 16,000 having drainage areas less than 0.5 square miles (Table 1). It is important to note that there are only a few 1^{st} order streams in the coastal plain with drainage areas of 2 square miles or more (approximately 0.2%).

Drainage area (Square miles)	**Number of potential sites in the Coastal Plain**
<0.1	11,896
0.1 – 0.5	4,913
0.5 – 1.0	1,099
1.0 – 2.0	268
2.0 – 3.0	30
3.0 – 4.0	5

Table 1. GIS based analysis of drainage areas within the Coastal Plain of Virginia by drainage basin size.

The Forested Headwater Wetland (FHW) subclass is unique in that it is partially defined in regulation by the average annual current flow (or lack thereof) in the associated ‘headwater’ stream (< 5 CFS). Present methodologies for determining the limit of headwater wetlands range from the ability of the delineator to leap over the stream (or not) to the tenuous, almost equally variable, relationship between the drainage area and adjacent stream flow (i.e. 1 square mile of drainage area equals 1 CFS). The first step to developing an HGM model for the FHW subclass was to determine the extent of these systems by determining where the annual average 5 CFS (and 1 CFS) flow breakpoint occurs and relating that measurement to drainage area. Data from an initial headwater study (Havens et al. 2005) of six headwater sites showed average CFS flows ranging from < 0.1 to 2.72 with drainage areas in square miles ranging from 0.08 to 2.21.

Physical geomorphology defines the ecosystem function of headwater wetlands and can be expected to be different across physiographic regions (i.e. coastal plain to piedmont to ridge and valley). The reduction in gradient in the flatter coastal plain generally results in greater frequencies of overbank flows, a flatter hydrograph, and longer periods of inundation (Hupp 2000).

This study refines the framework for development of variables associated with disturbance by defining the geomorphic reference for headwater wetland systems in the coastal plain of Virginia.

Methods

Based on information from the previous study we established continuously recording stream gages (RDS Ecotone™), set to record hourly, on an additional ten (10) headwater wetland streams (total sites equal seventeen – Appendix A). A hand-held current meter (Flowtracker™) and a salt-dilution method utilizing a YSI Sonde (Appendix B, G. Hancock, per. com.) were used at specific sampling stations to periodically calibrate stream velocity with gage level to produce a gage level/flow velocity curve. In a comparison of flow determination methodologies, the salt-dilution method was determined to be more accurate in most situations, particularly low flow streams. The drainage area of the study sites was determined by using the USGS National Elevation Dataset (NED). The NED is used to generate a 'flow direction' using the GIS (Geographic Information System) ESRI hydrologic tools. The NED generated drainage areas were field-verified using hand-held GPS units and topographic maps.

GIS tools were used to overlay the National Wetlands Inventory (NWI) maps with stream coverage to calculate the amount of wetlands associated with the headwater streams. The NWI coverage was field-verified. On two sites, wetlands were present but not depicted by the NWI. The extent of these wetlands was determined using standard delineation methods (Environmental Laboratory, 1987).

Field sampling included stream incision ratios, plant community composition, total dissolved nitrogen (TDN), instream woody debris, invasive species and fauna community structure. To measure a potential shift in plant community over time due to stream incision, incision ratio (bank height / bank full height) was compared with tree wetland indicator status / sapling indicator status ratios.

Incision ratios were calculated by sampling 1m intervals along a 50m stream segment and measuring bankfull and bank height (Rosgen 2001). TDN was sampled monthly at each site and analyzed in the laboratory by a SKALAR SANplus Continuous Flow Analyzer. Trees were sampled by the Bitterlich plotless method (Basal Area Factor = 2) at three areas and measuring the diameter at breast height (DBH) and recording species. All woody stems >1m tall and < 5 cm DBH in three 1.9 m radius plots were recorded for each Bitterlich sample point. Cover was estimated for all woody vegetation < 1m tall, herbs, and invasive species in each 1.9m radius plot and placed in cover classes using the midpoint protocol (Table 2). The volume of in-stream woody debris (> 5cm DBH) was measured by the intercept method along a 50m transect in the stream.

Cover Class	Mid-Point
0-5	2.5
5-25	15
25-50	37.5
50	50
50-75	62.5
75-95	85
95-100	97.5

Table 2. Cover classes and mid-points (Mueller-Dombois and Ellenberg 1974)

Automatic sound recording devices were deployed during the summer to all headwater wetland sites to test relationships between the ecological service of providing habitat for birds and amphibians. The system recorded the sound signature of each site by recording a fifteen-minute segment at 6:00am and 9:00pm for three consecutive days. Site stress level was determined using an onsite stressor checklist (Havens et al. 2006).

Results

Drainage Area and Flow

Wetland acreage associated with the headwater systems ranged from 0.5 to 51.8 (Table 3). No headwater wetland system had an average flow greater than 5 CFS and only 38% of the sites had average flows greater than 1 CFS. There was a direct relationship between drainage area (mile^2) and headwater stream flow (CFS) suggesting that in the coastal plain flow will be between 64% and 79% of the drainage area (Figure 1).

Site	Drainage area (Square miles)	Average Discharge (CFS) 03/2003-10/2004		Ave. Discharge (CFS) 05/05-10/06		Wetland area (acres)
C1	1.00	0.97[1]		0.42[1]		13.8
C2	1.43	1.98	89% over 1 CFS 0.7% over 5 CFS	0.85	7.0% over 1 CFS 0.2% over 5 CFS	21.4
C4	0.97	2.72	100% over 1 CFS 5.9% over 5 CFS	0.65	7.0% over 1 CFS 0.9% over 5 CFS	2.7
T[3]	0.99	NA		NA		19.7
Chl	0.29	1.29	46.9% over 1 CFS 1.7% over 5 CFS	0.34	3.0% over 1 CFS 0.1% over 5 CFS	1.9
D	2.21	1.86[2]		NA		51.8
Wy	0.08	< 0.1		<0.1		2.0
Bd	2.64	NA		2.10	91.1% over 1CFS 1.9% over 5 CFS	5.0
Bs	0.42	NA		0.07	0.0% over 1 CFS 0.0% over 5 CFS	3.8
Chs	0.31	NA		0.43	8.3% over 1 CFS 0.9% over 5 CFS	6.6
Cl	0.89	NA		0.61	18.0% over 1 CFS 0.1% over 5 CFS	2.3
E	0.59	NA		0.55	9.1% over 1 CFS 0.3% over 5 CFS	5.0
M	0.36	NA		0.22	1.0% over 1 CFS 0.1% over 5 CFS	2.4
L	4.31	NA		3.45[1]	NA	3.0
R	3.68	NA		1.46	90.0% over 1 CFS 0.0% over 5 CFS	1.3
Wd	0.26	NA		0.05	0.2 % over 1 CFS 0.01% over 5 CFS	0.5
Z	0.53	NA		0.61	25.0% over 1 CFS 0.01% over 5 CFS	5.4

Table 3. Amount of wetlands associated with headwater streams in drainage basins of various size and average CFS discharge.[1]Flow calculated by monthly Flow Tracker measurements only. [2]Potential beaver dam flow modification after gage installation. [3] Site abandoned after beaver dam construction inundated area.

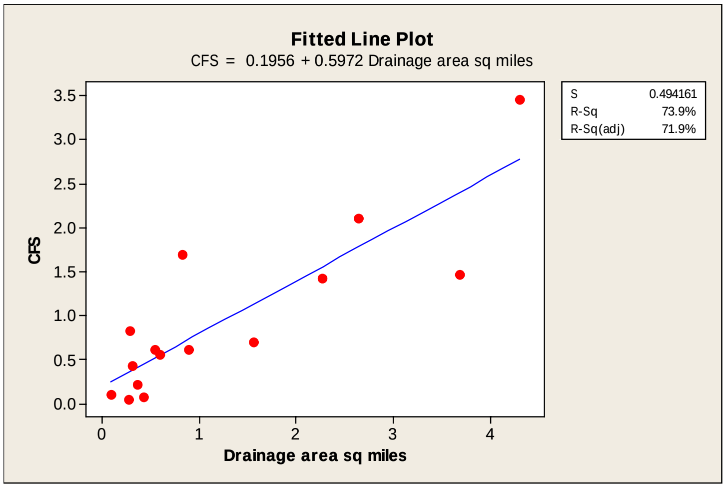


Figure 1. Relationship between drainage area and average flow (R-sq = 71.9%, p < 0.001)

It is important to note that only two sites had average CFS flows greater than 2.0 during the study period. Year 2003 was considered an above normal year for precipitation and included a direct hit from a Category 1 hurricane (Isabel), 2004 was considered a near-record precipitation year, 2005 was a below normal precipitation year, and 2006 was slightly above average with two extreme weather events (tropical depressions Alberto and Ernesto). In addition, two sites had drainage areas of 0.08 $mile^2$ and 0.59 $mile^2$ that included wetlands not mapped by the National Wetlands Inventory (NWI) of 2 acres and 5 acres, respectively. Taken cumulatively, the wetlands associated with the 14 sites where the CFS average flow was under 2.0 totaled 140.6 acres with the total suite of sites fitting a linear relationship (R-sq = 71.9%, p < 0.001) between amount of wetlands and drainage area (Figure 2). This data suggests that in the coastal plain a significant amount of wetlands may be associated with headwater streams that have an average annual CFS flow less that 5.0 (or even 2.0).

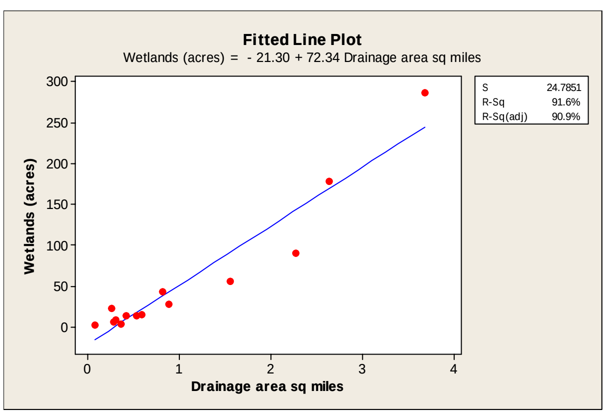


Figure 2. Relationship between drainage area and wetland acreage (R-sq = 90.9%, p < 0.001). One anomalous site was removed due to excessive development (approximately 70% developed land in drainage area).

Headwater Wetland Stream Incision

There is a strong positive correlation (Pearson = 0.78, p = 0.001) between increasing headwater stream incision and an increasing shift from wetter tree species to drier sapling species with a significant linear relationship (R-sq = 41.8%, p = 0.004) (Figure 3). The cover estimate of invasive species within headwater wetlands shows a strong linear relationship with increased stream incision (R-sq = 32.9%, p = 0.012) (Figure 3). In addition, there is a strong positive correlation (Pearson = 0.77, p < 0.001) between the amount of developed land within the wetland drainage area and headwater wetland incision ratio with a significant linear relationship (R-square = 23.2%, p = 0.043) (Figure 4).

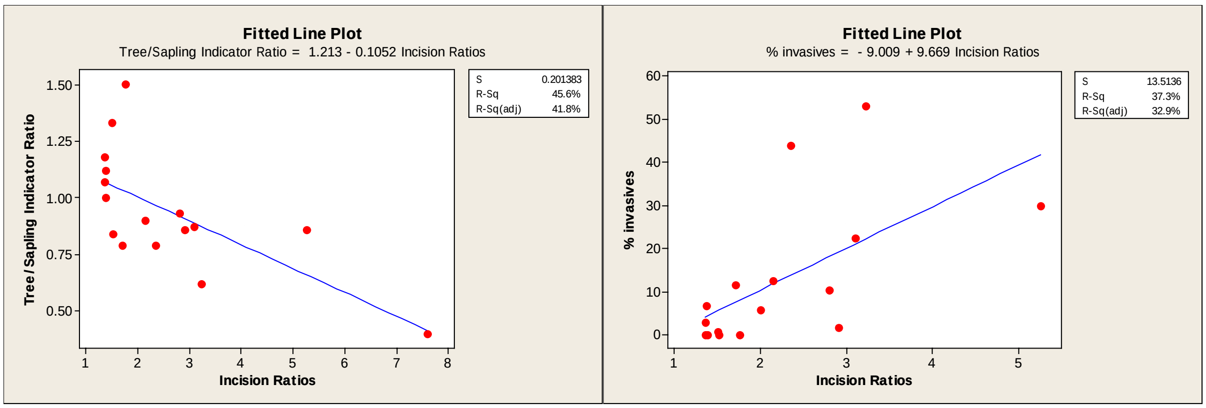


Figure 3. A. Tree/sapling wetland indicator status ratio versus incision ratio. Ratios below 1.0 indicate a shift toward more upland species, R-Sq = 41.8%, p = 0.004. B. Percent invasive species cover versus incision ratio, R-Sq = 32.9%, p = 0.012.

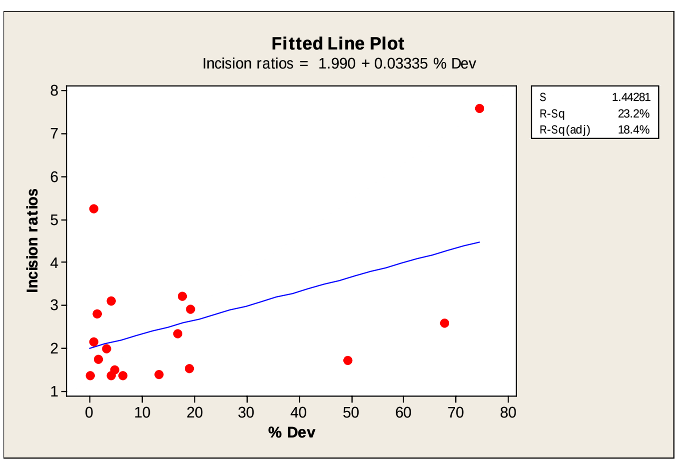


Figure 4. Relationship between total developed land within the wetland drainage area and wetland stream incision ratio (R-sq = 23.2%, p = 0.043).

Landuse and Water Quality Affects

There is a strong linear relationship between land use within the contributing drainage area of the headwater wetland and nitrogen loading to the headwater streams (Figure 5). The strongest relationship is between the percent of land in pasture and the increase in stream TDN (R-sq = 68.3%, $p < 0.001$).

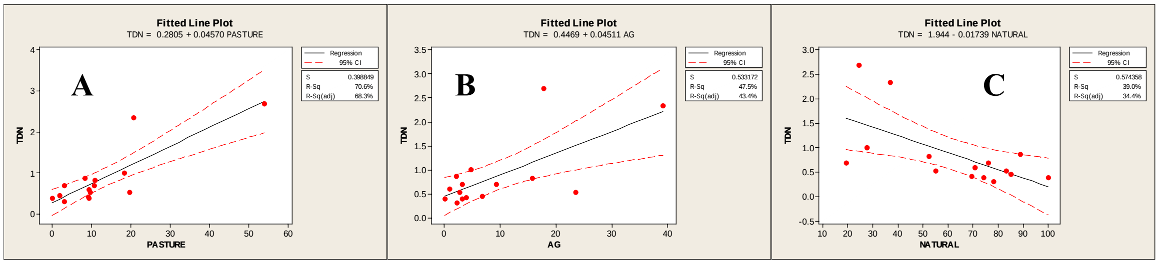


Figure 5. Total dissolved nitrogen (TDN) versus percent land in drainage area in various land use types: A) pasture, B) cropland, and C) natural. R-sq = 68.3%, $p < 0.001$; R-sq = 43.4%, p = 0.004; and R-sq = 34.4%, p = 0.013, respectively.

<u>Landuse and Habitat Affects</u>

Avian and amphibian community sound signature (Figure 6) similarities were examined with nonparametric multidimensional scaling (nMDS) and analysis of similarities (ANOSIM) in PRIMER 6.0 (Clarke and Warwick 2001). MDS ordinates sites based on similarities in sound signature makeup, using rank order of distances to map out relationships. Sites with high similarity are placed close together on the MDS map. A Euclidean distance coefficient was used to calculate the similarity matrix. Factors were overlaid on MDS plot to visualize community groupings in relation to headwater wetland features, such as land use and stress level. Subsequently, ANOSIM was used to test relationships among land use and stress level. Similarities were evident between 1) sites with significant pasture land, 2) sites that had low to medium stress, and 3) highly stressed sites (Figure 7).

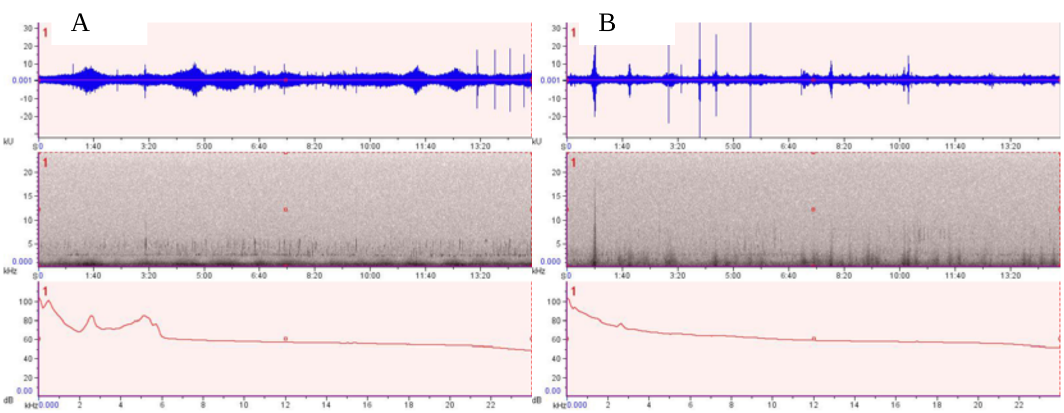


Figure 6. Spectrum slice of sound signatures between an unstressed site (A) and a stressed site (B).

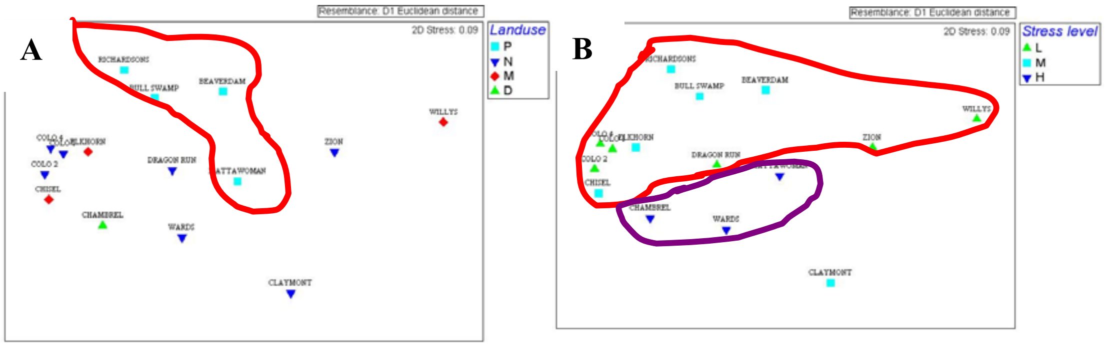


Figure 7. Avian and amphibian community sound signature similarities analyzed by A) land use and B) stress level (nonparametric multidimensional scaling and analysis of similarities).

<u>Perennial and Intermittent Classification</u>

Two of seven headwater sites showed intermittent flows as indicated by overlapping air and stream bottom temperature signals (Figure 8). Gage readings showed 0.0 CFS flow for the two intermittent sites during the temperature-derived intermittent flow periods and continuous perennial flows for the other sites (Table 4). The level of disturbance to the hydrology of the headwater sites may be reflected in the level of temperature fluctuation between the air and stream bottom temperature signals. Further investigation into specific hydrologic stressors and headwater stream temperature modifications is warranted.

Site	Drainage area ($mile^2$)	Flow (CFS Averaged over 2005-2006 study period)	Perennial/Intermittent Status
Wd	0.26	0.05	Intermittent
Chl	0.29	0.34	Perennial
Chs	0.31	0.43	Perennial
BS	0.42	0.07	Intermittent
C4	0.97	0.65	Perennial
C1	1.00	0.42	Perennial
C2	1.43	0.85	Perennial

Table 4. Perennial/Intermittent status of seven headwater wetland sites.

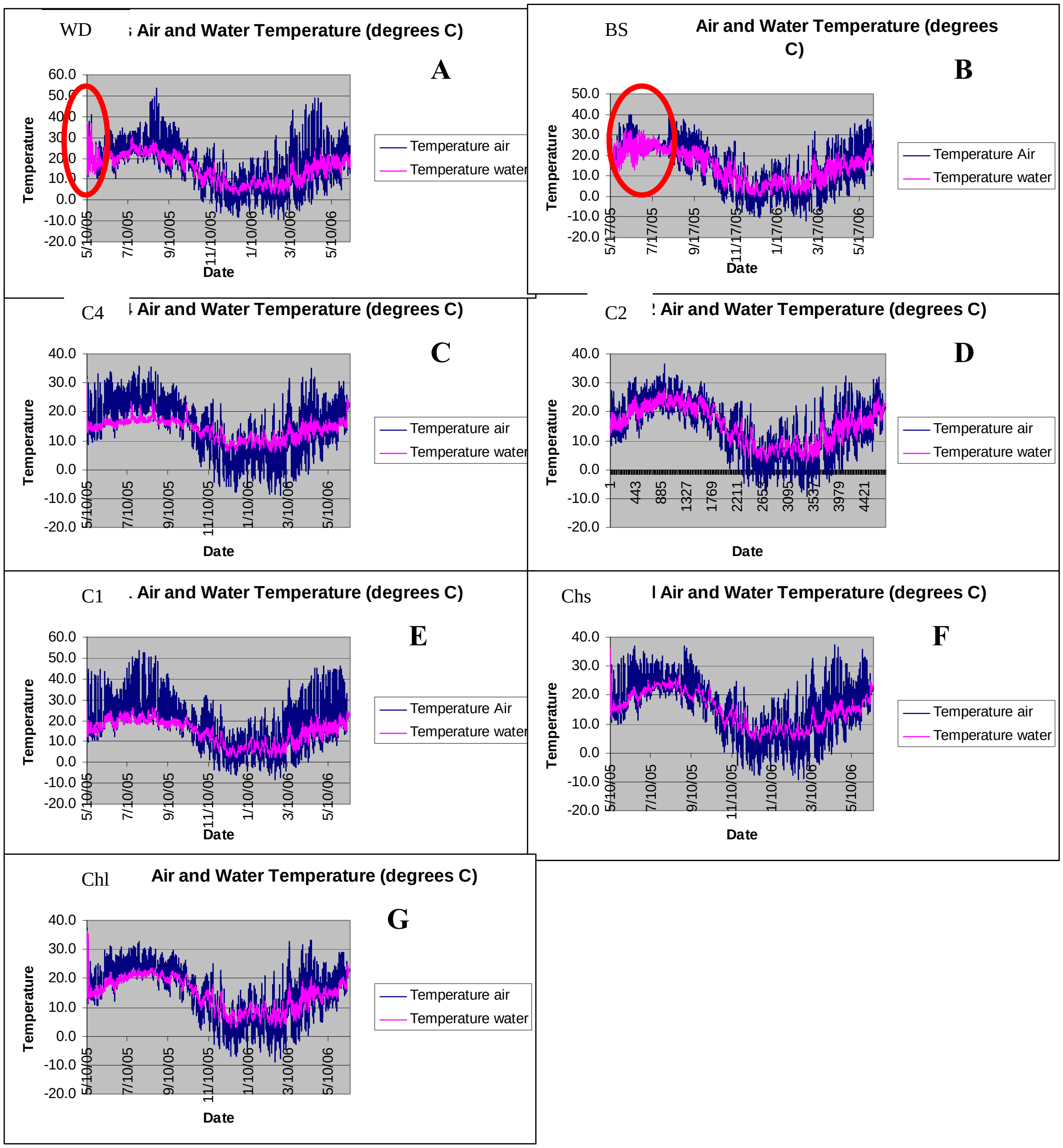


Figure 8. Comparison of air and stream bottom temperatures in seven headwater sites. Sites A and B both went dry (intermittent flow) during the study period as indicated by the overlapping air and stream temperatures (areas circled in red). All other sites had continuous flows (perennial).

Discussion

Virginia's nontidal regulations allow for the issuance of a general permit for the loss of 2 acres of wetlands regardless of whether the wetlands are associated with headwater systems. The Commonwealth presently defines perennial streams as "a stream that has flowing water year round in a typical year. For the purpose of this chapter, a surface water body (or stream segment) having a drainage area of at least 320 acres (0.5 square mile) is a perennial stream, unless field conditions clearly indicate otherwise" (VAC 25-660-10 et seq.). The perennial versus intermediate stream designation is important in Virginia's regulations for establishing setback distances from wetlands and surface waters connected to the Chesapeake Bay. Data from this study suggests that some headwater streams in Virginia's coastal plain with drainage areas less than 0.5 $mile^2$ are perennial with a significant amount of associated wetlands.

It is vitally important to validate the effects of various disturbances on the biotic endpoint of concern. The assumption that disturbances and stressors affect biotic function is the underpinning of the Hydrogeomorphic Functional Assessment and other functional assessment models. To this end, it is important to collect data to validate the disturbance gradient concept in forested headwater wetland systems. This data can be used as the foundation for final HGM model development for forested headwater wetland systems and provide needed biological data to further clarify and define headwater streams and wetlands in relation to long-term hydrological conditions. Water quality and habitat functions are generally two of the more prominent functions of concern when assessing wetland condition.

Data from this study suggests that landcover types, particularly development within the drainage area, can incise the headwater stream resulting in a draw-down of the water table from the immediately adjacent wetlands and reduce groundwater discharge to, and overbank flooding of, the adjacent wetlands. This can effect the overall water quality and habitat function of headwater wetlands by replacing the wetland tolerant vegetation with more upland vegetation, bypassing the runoff filtering capacity of the wetland, and reducing available habitat for wetland and stream fauna. Roads have been shown to impact water quality and habitat function (Forman et al. 2003, Jochen et al. 2005). Due to the strong correlation between roads (m/acre) and percent developed land (Pearson = 0.62, $p = 0.01$), developed land can be used as an inclusive variable for determining landscape functional impacts. In addition, surrounding landuse has an affect on headwater wetlands by increasing nitrogen loading to the headwater system and modifying the fauna community.

This study suggests the following variables with scaling (thresholds) for developing headwater wetland HGM functional formulas.

<u>Water Quality Integrity</u>

- Decreasing water quality function when the headwater wetlands drainage area within 200m has greater than approximately 15% pasture, or greater than approximately 20% cropland, or natural cover less than approximately 70%.

- Decreasing water quality function for headwater wetlands when the stream associated with system has an incision ratio greater than 2.

Habitat Integrity

- Decreasing habitat function for headwater wetlands when the surrounding landscape within 200m is greater than approximately 10% developed.

- Decreasing habitat function for headwater wetlands when the stream associated with system has an incision ratio greater than 2.

Acknowledgements

The authors are grateful to a number of individuals for their assistance with site access including York River State Park, Colonial Historic Park, Newport News Waterworks, Chesapeake Bay National Estuarine Research Reserve, and Susan Moniak of Brookdale Chambrel at Williamsburg provided site assess. Special thanks to Dr. Greg Hancock and Mr. Sam Austin for technical advise.

Although the research described in this article has been funded wholly or in part by the United States Environmental Protection Agency through a State Wetland Program Development Grant, it has not been subjected to the Agency's required peer and policy review and therefore does not reflect the view of the Agency and no official endorsement should be inferred.

References

ANPRM. 2003. Advanced Notice of Proposed Rulemaking, January 12, 2003. Environmental Protection Agency, Office of Water and U.S. Army Corps of Engineers.

Brinson, M.M. 1993. Changes in functioning of wetlands along environmental gradient. Wetlands 13: 65-74.

Clark, K.R. and R.M. Warwick. 2001. Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E: Plymouth.

Cooper, J.R., W. Gilliam, R.B. Daniels and W.P. Robarge. 1987. Riparian areas as filters for agricultural sediment. Soil Sci. Soc. Am. J. 51: 416-420.

Environmental Laboratory. 1987. Corps of Engineers Wetlands Delineation Manual. Technical Report Y-87-1. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

EPA. 2003. Consolidated EPA Region III response to the Advanced Notice of Proposed Rulemaking on the Clean Water Act regulatory definition of "Waters of the United States". Philadelphia, PA.

Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C.D., Dale, V.H., Fahrig, L., France, R., Goldman, C.R., Heanue, K., Jones, J.A., Swanson, F.J., Turrentine, T., Winter, T.C., 2003. Road Ecology. Science and Solutions. Island Press, Washington, 481 pp.

Havens, K.J., D. O'Brien, T. Rudnicky, D.Stanhope, K. Angstadt, D. Schatt, and C. Hershner. 2006. Development of a Nontidal Wetland Inventory, Condition Assessment, and Monitoring Strategy for Virginia 1.3. Final Report to USEPA.

Havens, K.J., D. O'Brien, D. Stanhope, D. Schatt, K. Angstadt, T. Rudnicky, and C. Hershner. 2005. Initiating development of a HGM model for headwater wetlands in the coastal plain of Virginia. Final report to the USEPA, EPA CD # 983596-01.

Hession, W.C., J.E. Pizzuto, T.E. Johnson and R.J. Horwitz. 2003. Influence of bank vegetation on channel morphology in rural and urban watersheds. Geology 31(2): 147-150.

Hupp, C.R. 2000. Hydrology, geomorphology and vegetation of coastal plain rivers in the south-eastern USA. Hydrological Processes 14: 2991-3010.

Jaeger, R.G. 1994. Transect sampling. Pp 103-107 in: Heyer, R.H., M.A. Donnelly, R.W. McDiarmid, L.C. Hayek and M.S. Foster (eds.). Measuring and monitoring biological diversity: Standard methods for amphibians. Smithsonian Institution Press, Washington, D.C.

Jochen A.G. Jaeger, J. Bowmanb, J. Brennan, L. Fahrig, D. Bert, J. Bouchard, N. Charbonneau, K. Frank, B. Gruber, K. Tluk von Toschanowitz. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. Ecological Modelling 185: 329–348.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, Inc.

Peterjohn, W.T. and D.L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observation on the role of a riparian forest. Ecology 65: 1466-1475.

Peterson, B.J., W.M. Wollheim, P.J. Mulholland, J.R. Webster, J.L. Meyer, J.L. Tank, E. Marti, W.B. Bowden, H.M. Valett, A.E. Hershey, W.H. McDowell, W.K. Dodds, S.K. Hamilton, S. Gregory, and D.D. Morrall. 2001. Control of nitrogen export from watersheds by headwater streams. Science 292: 86-90.

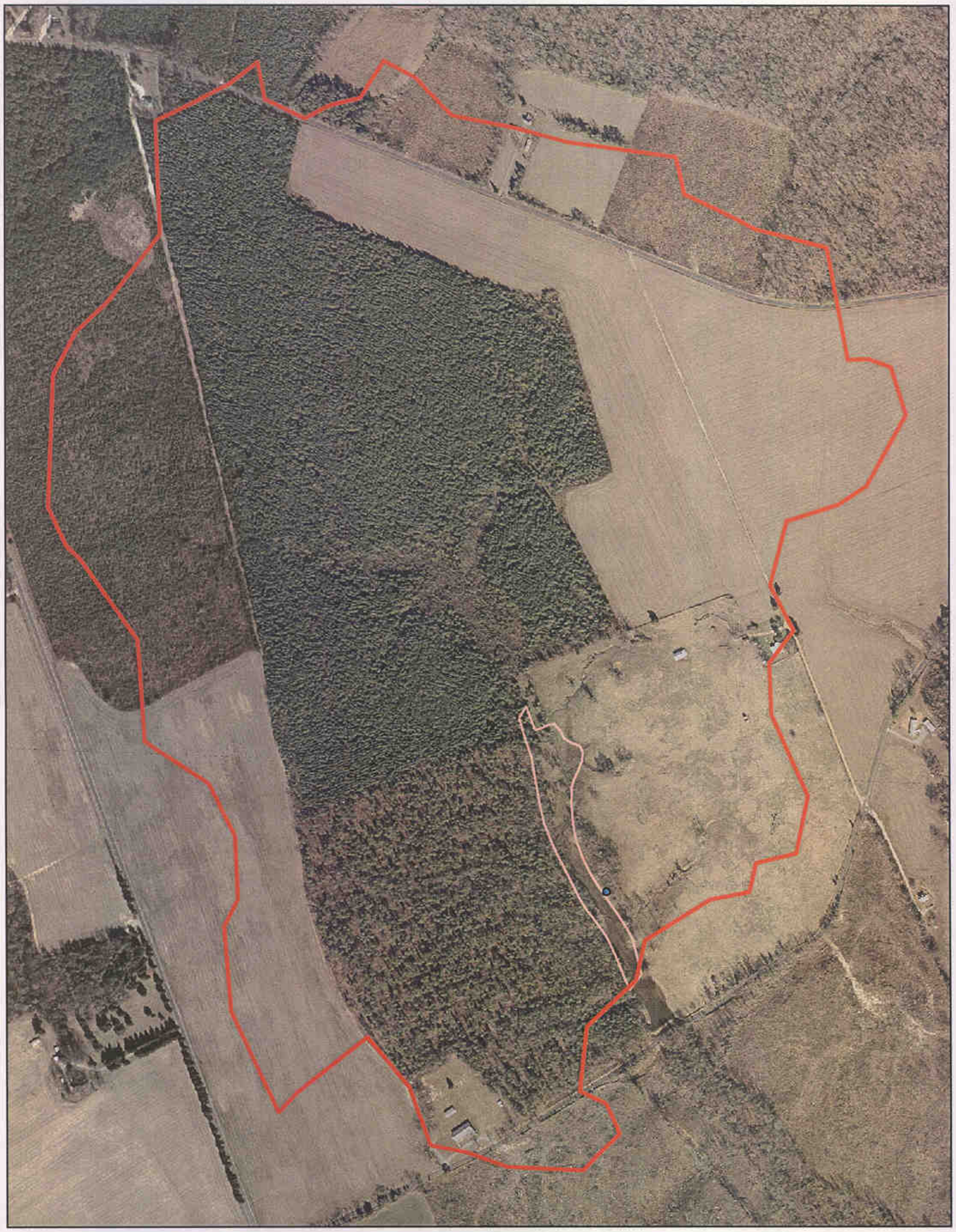
Rosgen, D. L. 2001. A Practical Method of Computing Streambank Erosion Rates, Proceedings of the 2001 Federal Interagency Sediment Conference, March 25-29, Reno, Nevada.

Spingarn, A. 2003. The extent, function and values of headwater wetlands and streams in the Mid-Atlantic region. USEPA region III, Sixth Wetlands Workshop, Oct 27-30, 2003, Atlantic City, NJ.

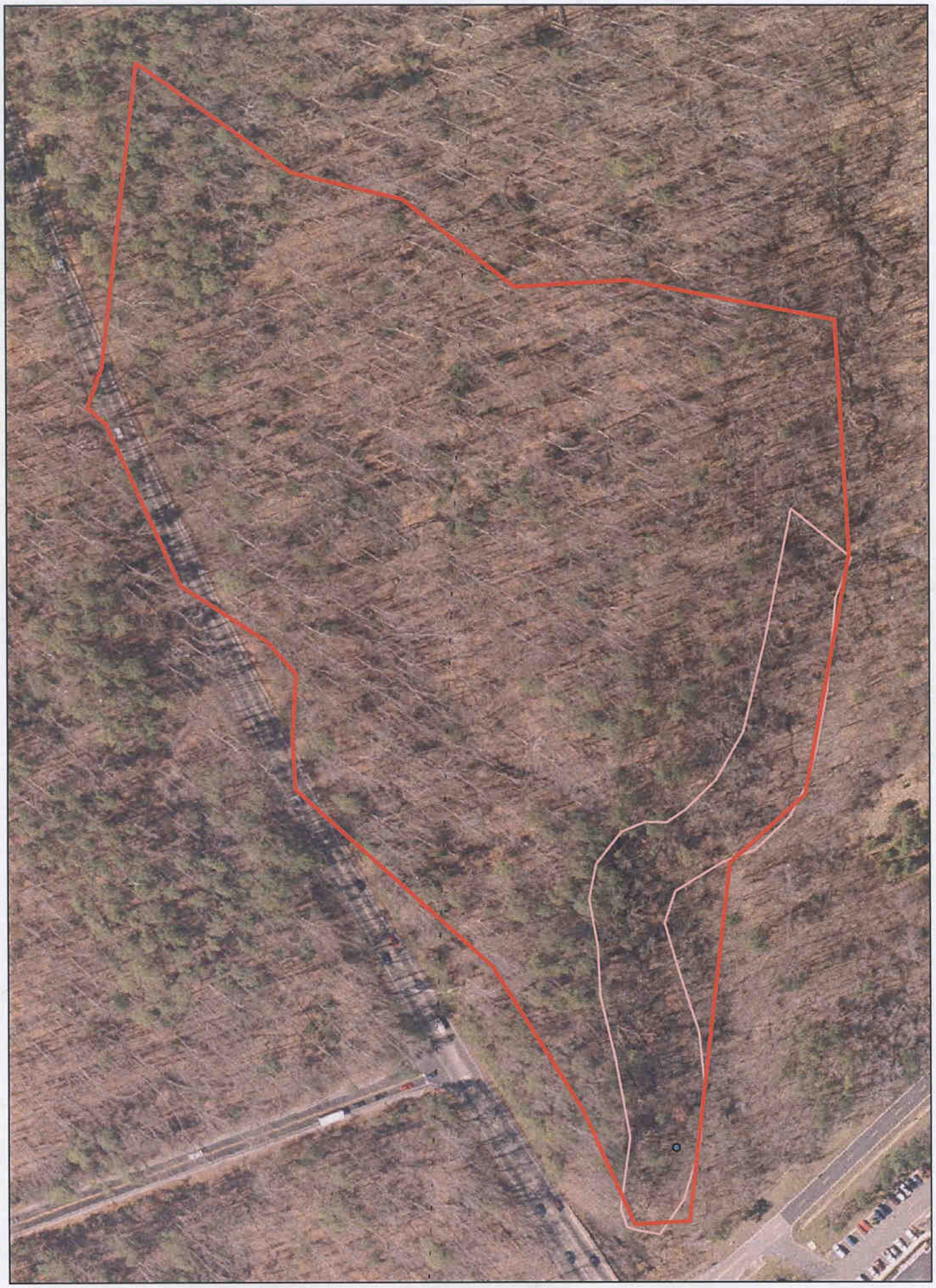
Appendix A. Site aerial photographs (Aerial Imagery 2002 Commonwealth of Virginia)

BD

BS



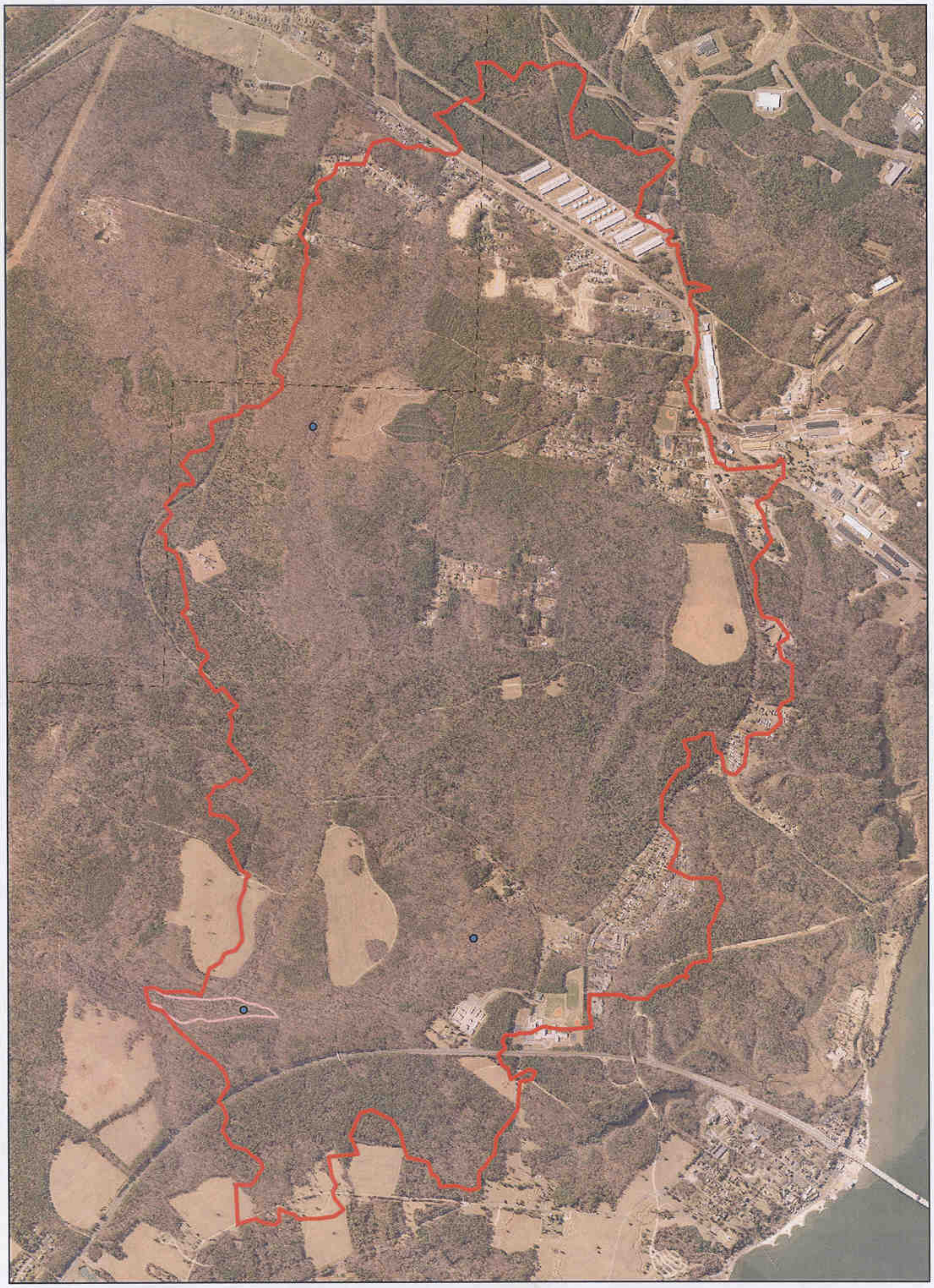
Chl



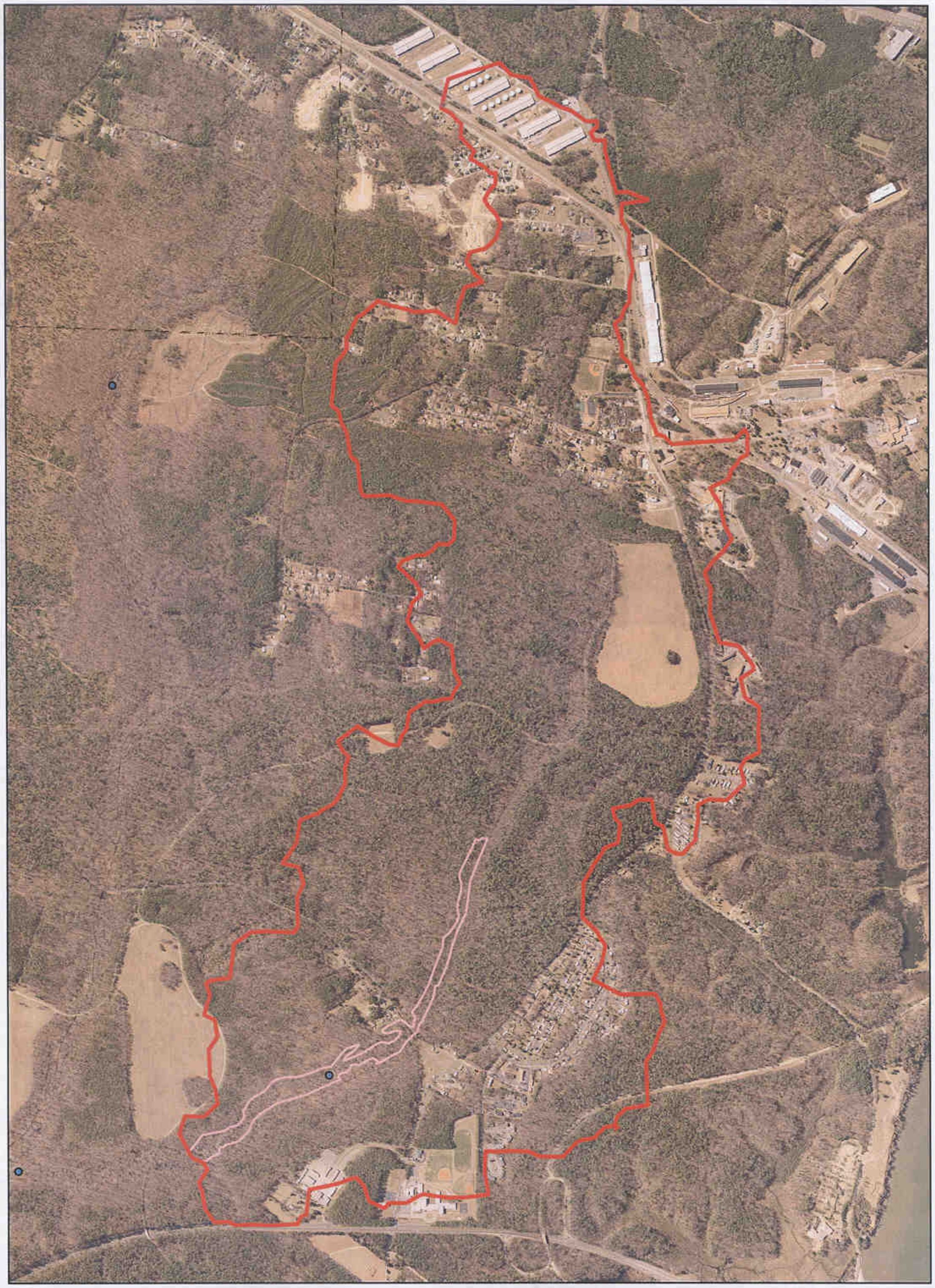
Chs

Cl

C1

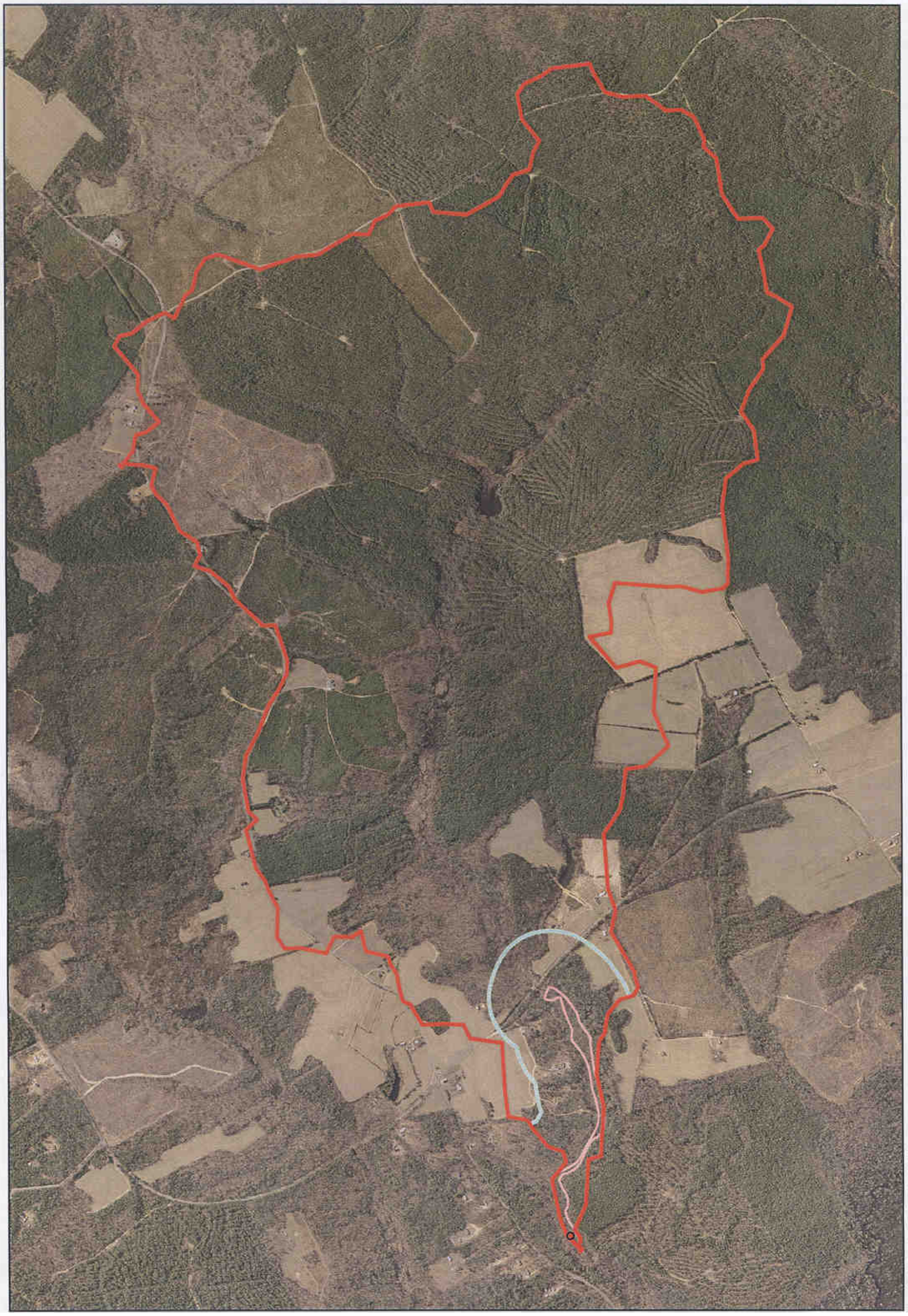


C2



C4

D

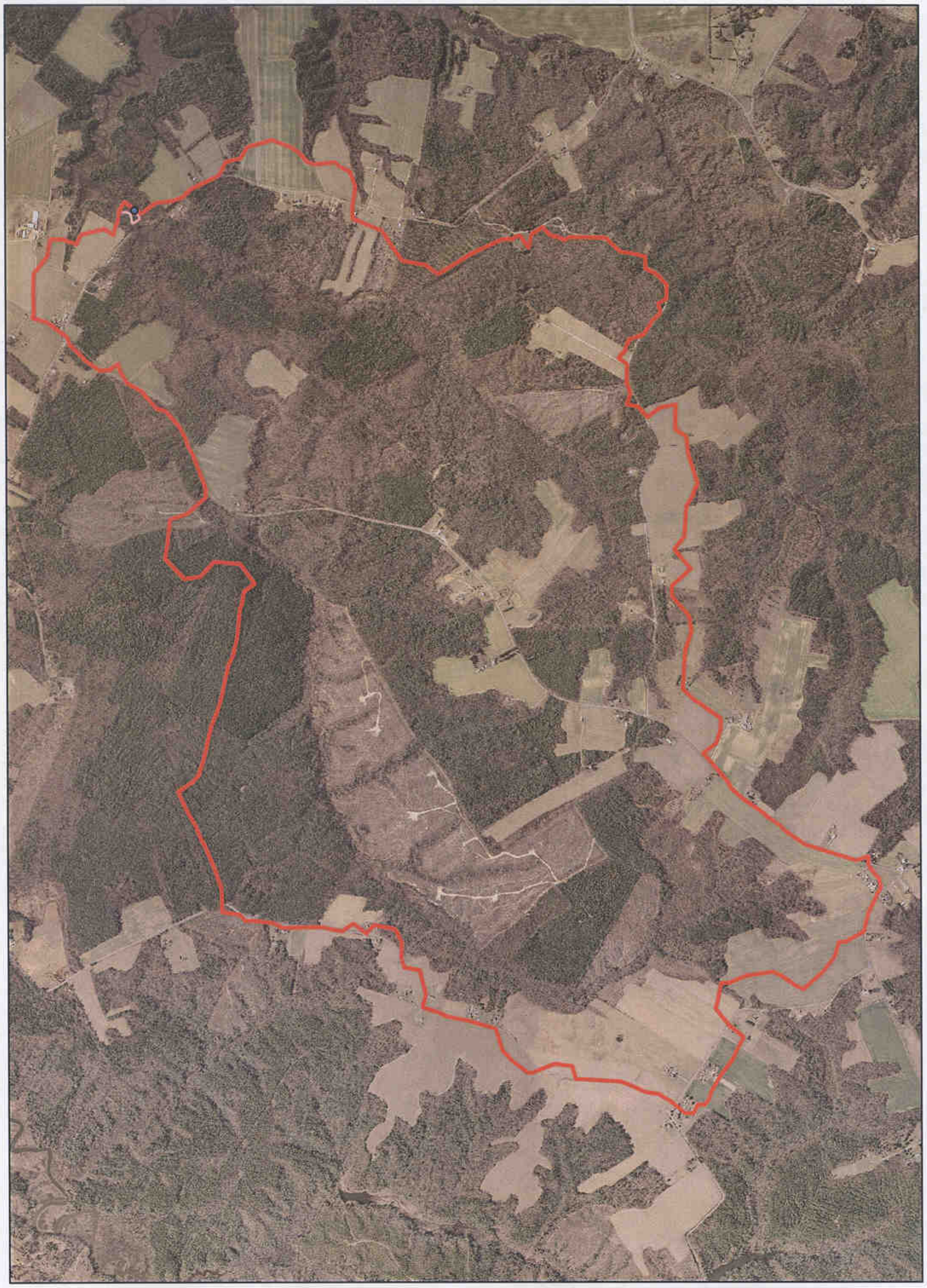


E

L

M

R



Wd

Wy

Z

Appendix B. Salt dilution stream discharge calculation.

$$Q = \frac{M_S}{\sum_{i=0}^{n}(C_i - C_B)\Delta t}$$

C_i = concentration of tracer measured at some point in time.
C_B = background concentration.
M_S = mass of salt added.
Δt = time interval between measurements.