APPENDIX A

SUMMARY OF THE PHASE I SAMI AQUATIC AND TERRESTRIAL ASSESSMENT

Summary of Phase I Results

Results of Phase I of the SAMI aquatic and forest assessment were presented by Cosby and Sullivan (1999), Munson et al. (1999), and Brewer et al. (2000). Three watersheds were calibrated to each of the two models and ten deposition scenarios were conducted. The scenarios included various levels of future changes in SO_4^{2-} and NO_3^- deposition, and in two cases also base cation deposition. Major findings are summarized below.

The scenarios were based on percentage changes in SO_4^{2-}, NO_3^-, and (in some cases) base cation deposition relative to deposition of these ions in a reference year (1995). All other ions in deposition were assumed to remain constant into the future at the reference year levels. The reference year deposition for each site was based on the volume weighted annual average total deposition of each ion. For each scenario, simulations were run for forty-five years into the future (1996-2040). For the scenarios assuming either increased or decreased deposition of an ion, the deposition increases or decreases were implemented as a step change in 1996 and the deposition of the changed ions was maintained constant at the new level until the year 2040. Deposition was the only input or parameter changed in the scenarios. Soil characteristics, hydrological responses and biological dynamics were all assumed to be constant into the future (at reference year values) for each scenario.

The ten future atmospheric deposition scenarios used for the MAGIC and NuCM simulations for each site in SAMI Phase I were:

Scenario 1	No changes
Scenario 2	30% reduction in sulfate, 20% decrease in nitrate
Scenario 3	30% reduction in sulfate, 20% increase in nitrate
Scenario 4	50% reduction in sulfate, 40% decrease in nitrate
Scenario 5	50% reduction in sulfate, 20% increase in nitrate
Scenario 6	30% reduction in sulfate, 20% increase in nitrate, 20% decrease in calcium, magnesium, sodium, and potassium
Scenario 7	70% reduction in sulfate, 20% decrease in nitrate
Scenario 8	70% reduction in sulfate, 20% increase in nitrate
Scenario 9	70% reduction in sulfate, 40% decrease in nitrate
Scenario 10	70% reduction in sulfate, 20% decrease in nitrate, 20% decrease in calcium, magnesium, sodium, and potassium

MAGIC

Comparisons of simulated and observed monthly average stream ANC (an integrated measure of overall model goodness-of-fit) for each Phase I site indicated that the model could successfully reproduce observed streamwater quality at all three SAMI Phase I sites. Results at each site are summarized below.

Noland Divide

MAGIC simulations with 0% or 30% reductions in SO_4^{2-} deposition resulted in increases in annual average stream SO_4^{2-} concentrations at Noland Divide. MAGIC simulations with 50% reductions in SO_4^{2-} deposition resulted in only slight increases (approximately 3 μeq/L) in annual average stream SO_4^{2-} concentrations (relative to the reference year) whereas 70% reductions in SO_4^{2-} deposition resulted in slight decreases (approximately 3 μeq/L). These simulation results suggested that reductions of SO_4^{2-} deposition of 50% to 70% (relative to the reference year) would be necessary to prevent further increases in annual average stream SO_4^{2-} concentrations at Noland Divide.

MAGIC simulations of changes in annual average stream NO_3^- concentrations in response to changes in NO_3^- deposition suggested that Noland Divide water quality is responsive to NO_3^- deposition, with responses to changed NO_3^- deposition being relatively rapid. The magnitude of changes in annual average stream NO_3^- concentrations were proportional to the changes in atmospheric NO_3^- deposition.

Of the ten scenarios considered for Noland Divide, one scenario resulted in increased simulated annual average ANC (scenario 9), two scenarios resulted in essentially no change in simulated annual average ANC (± 10% of reference year alkalinity; scenarios 4 and 7). The remaining seven scenarios resulted in declines in simulated annual average ANC (scenarios 1,2, 3, 5, 6, 8, and 10). Four scenarios resulted in simulated annual average ANC that was less than zero (scenarios 1, 3, 5, and 6). These results suggested that, for Noland Divide, reductions in the total acidity of deposition of at least 55% (relative to the reference year), would be necessary to prevent annual average stream ANC from becoming negative.

North Fork Dry Run

MAGIC simulations with 0% change in SO_4^{2-} deposition resulted in slight increases in annual average stream SO_4^{2-} concentrations at North Fork Dry Run. MAGIC simulations with 30%, 50%, and 70% reductions in SO_4^{2-} deposition all resulted in declines in annual average stream SO_4^{2-} concentrations. These simulation results suggested that the catchment at North Fork Dry Run is nearly at steady state with respect to SO_4^{2-} deposition (i.e., SO_4^{2-} output flux equals SO_4^{2-} input flux). Reductions in SO_4^{2-} deposition will likely result in declines in annual average stream SO_4^{2-} concentrations and the declines will be proportional to the magnitude of the deposition reduction.

MAGIC simulations of changes in annual average stream NO_3^- concentrations in response to changes in NO_3^- deposition suggested that North Fork Dry Run water quality was somewhat responsive to NO_3^- deposition, with responses to changed deposition being relatively rapid. However, the simulated changes in annual average stream NO_3^- concentrations were relatively small, and there was not a large difference in response across the scenarios.

Of the ten scenarios considered for North Fork Dry Run, one scenario resulted in slightly increased simulated annual average ANC (scenario 9). Three scenarios resulted in declines in simulated annual average ANC of greater than 10% of the reference value (scenarios 1, 3, and 6). The remaining six scenarios resulted in essentially no change in simulated annual average ANC (± 10% in reference year ANC; scenarios 2, 4, 5, 7, 8, and 10). No scenarios resulted in simulated annual average ANC that was less than zero. Despite relatively large declines in simulated acid anion concentrations resulting from the deposition reductions in nine of the ten scenarios, the simulated ANC of the stream did not change significantly. These results suggested that North Fork Dry Run was not particularly sensitive to acidification and that no reductions in the total acidity of deposition (relative to the reference year) would be necessary to prevent annual average stream ANC from becoming negative.

White Oak Run

MAGIC simulations with 0% or 30% reductions in SO_4^{2-} deposition resulted in increases in annual average stream SO_4^{2-} concentrations at White Oak Run. MAGIC simulations with 50% reductions in SO_4^{2-} deposition resulted in approximately constant annual average stream SO_4^{2-} concentrations (relative to the reference year). Reductions of 70% in SO_4^{2-} deposition resulted in decreases in annual average stream SO_4^{2-} concentrations. These simulation results suggested that reductions of SO_4^{2-} deposition of 50% (relative to the reference year) would be necessary to prevent further increases in annual average stream SO_4^{2-} concentrations at White Oak Run.

The calibrated nitrogen dynamics at White Oak Run did not allow leakage of NO_3^- from the soils (in agreement with observed behavior in the calibration period). Plant and soil uptake in the catchment of White Oak Run apparently remove all deposited (and nitrified) N. This uptake capacity was not exceeded in any of the future deposition scenarios. The White Oak Run simulations were therefore unresponsive to simulated changes in atmospheric deposition of NO_3^-.

Of the 10 scenarios considered for White Oak Run, none resulted in increased simulated annual average stream ANC. All 10 scenarios produced declines in simulated annual average stream ANC that were greater than 10% of the reference value. Only four scenarios resulted in simulated annual average stream ANC that was significantly greater than zero (scenarios 7, 8, 9, and 10). Four scenarios resulted in simulated annual average ANC that was significantly below zero (scenarios 1, 2, 3, and 6). These results suggested that, for White Oak Run, reductions in the deposition of SO_4^{2-} of at least 50% (relative to the reference year) would be needed to prevent annual average stream ANC from becoming negative.

<u>Differences in Simulated Responses Across the Three Phase I Watersheds</u>

At Noland Divide, between 50% and 70% reductions in SO_4^{2-} deposition were needed in the simulations to prevent increases in stream SO_4^{2-}. At White Oak Run, at least 50% reductions in SO_4^{2-} deposition were needed for the same effect. At Shaver Hollow, however, any future reduction of SO_4^{2-} deposition in the simulations resulted in decreases in stream SO_4^{2-} concentrations. The simulations suggested the need for relatively large reductions in SO_4^{2-} deposition at Noland Divide and White Oak Run, and this resulted from the fact that the deposition input of SO_4^{2-} was greater than the output through stream discharge in 1995. The North Fork Dry Run catchment, however, had apparently reached an approximate steady state with deposition in 1995, and therefore any change in SO_4^{2-} deposition would lead to a corresponding change in streamwater SO_4^{2-} concentration.

These results suggested that the amount of SO_4^{2-} adsorption occurring in soils at Noland Divide and White Oak Run was greater than at North Fork Dry Run. Considering that the deposition of SO_4^{2-} is more than twice as great at Noland Divide than at either of the VA sites, we can rank the catchments in terms of SO_4^{2-} adsorption capacity (from greatest to least) as Noland Divide, White Oak Run, and then North Fork Dry Run.

All catchments were simulated to nitrify essentially all of the NH_4^+ deposited from the atmosphere, resulting in an increase in available NO_3^- in the soil. Both deposited NO_3^- and NO_3^- derived from nitrified NH_4^+ were then available for biological uptake and/or NO_3^- leaching in streamwater . Loss of atmospherically deposited NO_3^- through runoff was variable among the sites. The Noland Divide catchment had the highest proportional loss of NO_3^- (relative to deposition) of the three catchments (Noland Divide = 86% loss in runoff of deposited NO_3^-, North Fork Dry Run = 37%, White Oak Run = 1%). As with SO_4^{2-} retention, there was a ranking for NO_3^- retention (but it was different from that for SO_4^{2-}). The NO_3^- retention ranking indicated that White Oak Run was greater than North Fork Dry Run, which was greater than Noland Divide. MAGIC did not simulate any changes in the retention properties of the soils of the three catchments for any of the future scenarios. Therefore, the catchment with the strongest retention (White Oak Run) responded very little to the scenarios. Regardless of the change in NO_3^- deposition, whether up or down, the soils in the White Oak Run simulation still retained 99% of NO_3^- and there was no response in the stream. In that the NO_3^- was removed from solution in the soil, there was therefore no effect of changes in NO_3^- deposition on any other ion in the soil. The Noland Divide catchment had the lowest NO_3^- retention and therefore was the most sensitive to changes in NO_3^- deposition.

The relatively high retention of NO_3^- in the Virginia catchments relative to Noland Divide probably resulted from differences in vegetation dynamics at the sites. The high elevation spruce in Noland Divide are declining, reducing the overall vegetative demand for N in Noland Divide. The Virginia sites, on the other hand, are second growth forests, growing on relatively N-poor soils with a concomitant greater demand for atmospherically deposited N. The moderate leakage of NO_3^- from North Fork Dry Run was probably a 5 to 10 year transient response to the gypsy moth outbreak that occurred in the catchment. In the absence of gypsy moth infestation, nearly all the sites we have studied in the mountains of Virginia show complete retention of N.

The ANC responses of the streams varied in yet another pattern from that of SO_4^{2-} or NO_3^-. A 55% reduction in total deposition acidity was needed in the simulations to prevent loss of ANC in Noland Divide (i.e., to prevent ANC from declining to values less than zero). A 70%

reduction in total deposition acidity was needed for the same effect in White Oak Run. At North Fork Dry Run, however, none of the scenarios that were considered resulted in complete loss of ANC from the stream. Based on these results, we can classify White Oak Run as very sensitive to acidification Noland Divide as sensitive to acidification, and North Fork Dry Run as not sensitive.

The net production of ANC was approximately equal for North Fork Dry Run and Noland Divide. Even though Noland Divide produced more base cations than North Fork Dry Run, it also exported more acid anions, with the result that net buffering of acidity at Noland Divide was roughly equal to that at North Fork Dry Run. The net buffering of acidity at White Oak Run was about 25% lower than at the other two sites. The reason that simulations for North Fork Dry Run did not produce negative ANC for any scenario was that the starting values (in 1995) of ANC in North Fork Dry Run were higher. During the simulations, ANC values declined at all three sites. In Noland Divide, however, none of the scenarios drove the ANC to negative values.

Noland Divide was deemed to be moderately responsive to changes in SO_4^{2-} deposition, very responsive to changes in NO_3^- deposition, relatively sensitive to loss of ANC, and would require substantial decreases in total deposition acidity to maintain positive ANC in the stream.

North Fork Dry Run was very responsive to changes in SO_4^{2-} deposition, somewhat responsive to changes in NO_3^- deposition, relatively insensitive to loss of ANC, and would require only moderate decreases in total deposition acidity to maintain positive ANC in the stream.

White Oak Run was somewhat responsive to changes in SO_4^{2-} deposition, not responsive to changes in NO_3^- deposition, very sensitive to loss of ANC, and would require substantial decreases in SO_4^{2-} deposition to maintain positive ANC in the stream.

The responses to deposition represented by these three sites covered a range of behaviors that reflect variations in real catchment processes in the southern Appalachian Mountains. By applying the models to these three sites, we exercised the models across a range of responses that represent the qualitative and quantitative variations that would likely be encountered in the Phase II regional modeling assessment.

NuCM

The forest Nutrient Cycling Model (NuCM) is a PC-based model which simulates the processes that alter the acid-base properties of precipitation as it moves through the forest canopy, into and through watershed soils, and into surface waters. These processes include vegetation growth, litter fall and decay, soil biogeochemical processes, and water routing. The model can be used to simulate a forest plot or a forested watershed with a stream. Model output includes nutrient pool sizes in the soil and vegetation and fluxes between them. Nutrient concentrations in soil solution, throughfall, and streamflow, as well as sorbed concentrations, can be plotted versus time. Detailed cycle charts for key solutes are also produced.

NuCM was calibrated using existing data sets from the three selected watersheds. Noland Divide and Shaver Hollow were calibrated using observed inputs for the period 1991-1995. White Oak Run was calibrated using inputs for the period 1980-1985 to avoid the effects of a later gypsy moth infestation. Following calibration, deposition scenarios were run to determine how the systems respond to changes in deposition. These scenarios were based upon the average of observed deposition levels from 1991-1995 for all three watersheds.

Noland Divide

Streamwater concentrations of SO_4^{2-} at Noland Divide showed small responses to changes in atmospheric deposition of S. The range in streamwater SO_4^{2-} concentrations at the end of the simulations is 10-15 μeq/L even though input SO_4^{2-} concentrations were altered by up to 70 percent. Changes in NO_3^- deposition, however, did produce discernible changes in simulated streamwater NO_3^- concentrations, with final concentrations ranging from 20 to near 50 μeq/L. These changes in strong acid anion concentrations appeared to be largely compensated-for by changes in base cation concentrations, as reflected by relatively small changes in streamwater ANC for all scenarios simulated. The range of final ANC values is approximately 10-15 μeq/l.

Whereas the response of streamwaters to changes in S deposition were small, there were changes in the simulated concentrations of Ca^{2+} and Al^{n+} in the soil solution in the rooting zone at Noland Divide in response to 50 and 70 percent reductions in S deposition. These large deposition reductions resulted in Ca/Al ratios greater than 1 in 2040, indicating decreases in forest stress.

North Fork Dry Run

The simulated response to changing SO_4^{2-} deposition at North Fork Dry Run was generally similar to that observed at White Oak Run. Reductions in SO_4^{2-} deposition resulted in lower stream SO_4^{2-} concentrations, but changes in ANC were dampened as a result of changes in base cation concentrations. Changes in NO_3^- deposition resulted in changes in streamwater NO_3^- concentrations that were intermediate between those of White Oak Run and Noland Divide, but they appear to have little impact on ANC.

The soil solution response in the rooting zone at North Fork Dry Run was similar to that at White Oak Run in that Ca^{2+} concentrations decreased and Al^{n+} concentrations increased over time for all scenarios. Unlike White Oak Run, however, there were discernible differences among the various scenarios, with soil acidification being most severe for Scenario 1 (no change in deposition) and least severe for the 70 percent SO_4^{2-} deposition reduction scenarios. In addition, although soil acidification was taking place in the simulations, Ca/Al ratios below 1 were not observed for any of the scenarios by the year 2040.

White Oak Run

The response of White Oak Run streamwater was significantly different compared to that of Noland Divide. Simulated SO_4^{2-} concentrations increased to around 100 μeq/L for the reference year scenario (Scenario 1 - maintain 1995 deposition levels). These increased SO_4^{2-} concentrations were partially offset by cation exchange and weathering releases of base cations. The net result was a decrease in flow-weighted average annual ANC over the simulation period from just over 15 μeq/ L to around -5 μeq/L. Fifty and thirty percent reductions in S deposition resulted in smaller decreases in ANC, whereas seventy percent decreases in S deposition resulted in ANC concentrations in 2040 similar to those observed in the reference year. The response to changes in NO_3^- deposition are considerably dampened compared to the responses at Noland Divide and appear to have little impact on streamwater ANC values.

Soil solution concentrations in the rooting zone at White Oak Run showed steady declines in Ca^{2+} concentrations and increases in Al^{n+} concentrations for all scenarios over the simulation period. This is indicative of soil acidification. By 2040, the simulated Ca/Al ratio declined to values lower than 1 for all scenarios, which suggests that forest stress may increase over time.

References Cited

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