REVISED MEMORANDUM

To: Henry Ferland (EPA/OSW) and Ken Skog (USDA-FS)

From: Randy Freed, Anne Choate, and Sarah Shapiro

Date: February 27, 2006

Re: Revised Estimates of Effect of Paper Recycling on Forest Carbon

CC: Jeremy Scharfenberg, Susan Asam

1. Introduction and Summary

This memo presents estimates of the forest carbon sequestration that results from recycling or source reducing paper. These estimates are used in developing greenhouse gas (GHG) emission factors for the EPA Climate and Waste Program, which provides waste managers with information on the GHG implications of various management options (e.g., recycling, landfilling, combustion). Paper is the single largest category in the US municipal waste stream, both in terms of generation and recycling. Compared to other GHG sources and sinks in the life cycle of paper (e.g., CO_2 emissions associated with fossil energy use at paper mills), forest carbon storage is a major factor.

This revised memorandum reflects several improvements and additions subsequent to the previous (Dec 14, 2005) version, in response to peer review comments. It develops separate estimates of carbon storage for the two principal types of pulp, mechanical and chemical, based on their respective process yields in both virgin and recycled systems. It also incorporates a revised estimate of the proportion of recovered paper that is exported (40% in the current analysis, compared to 25 % previously). Although we investigated two other issues – the effect of changes in pulpwood harvest on sawtimber harvest, and the potential that reductions in pulpwood harvest might stimulate some land owners to convert from silviculture to other land uses – neither appeared to have a clear effect on the analysis and we did not quantify those effects. In addition, we use a different approach to estimate the effects of source reduction in this memo.[1]

The two prior editions of the Program's primary research report, *Solid Waste Management and Greenhouse Gases,*[2] rely on an analysis of forest carbon that was performed with the USDA-Forest Service in 1995, using models that were considered state-of-the-art at that time. Since 1995, there have been a number of improvements to those models, and EPA decided to revisit this issue to assure that the values used in developing life-cycle GHG emission factors are valid and reliable.

Forest carbon storage is very important in the context of national GHG emissions. When trees are cleared for agriculture or other activities, carbon is released (generally in the form of CO_2). On the other hand, when forests are planted and allowed to continue growing, they absorb

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[1] This revised memo also incorporates several review comments on a Feb 23, 2006 version, provided by Reid Miner and Jay Unwin of the National Council for Air and Stream Improvement (NCASI).

[2] The second edition is US EPA. 2002, Office of Solid Waste. EPA530-R-02-006. Washington, DC

atmospheric CO_2 and accumulate it in the form of cellulose and other materials. When the rate of uptake exceeds the rate of release, carbon is said to be stored.

In the United States, uptake by forests has long exceeded release, influenced by forest management activities and the reforestation of previously cleared areas. This net sequestration of carbon in forests represents a large and important process. EPA estimates that the annual net CO_2 flux (i.e., the excess of uptake minus release) in U.S. forests was about 146 million metric tons of carbon equivalent (MMTCE) in 2003,[3] offsetting about 8 percent of U.S. energy-related CO_2 emissions. In addition, about 16 MMTCE was stored in wood products currently in use (e.g., wood in building structures and furniture, paper in books and periodicals).

When paper and wood products are recycled or source reduced, trees that would otherwise be harvested are left standing. In the short term, this reduction in harvesting results in a larger quantity of carbon remaining stored, because the standing trees continue to store carbon, whereas paper and wood product manufacture and use tend to release carbon.[4] In the long term, some of the short-term benefits disappear as market forces result in less planting of new managed forests than would otherwise occur, so that there is comparatively less forest acreage in trees that are growing rapidly (and thus sequestering carbon rapidly).

This memo describes our method for updating the estimate of the effect of forest carbon storage associated with paper and wood product recycling and source reduction. The work was done as a cooperative effort between the U.S. Department of Agriculture Forest Service (USDA-FS), EPA, and ICF. This revised version of the memo can be reviewed by interested stakeholders, and is intended to serve as a basis for an update to the EPA report *Solid Waste Management and Greenhouse Gases*[5] (and potentially, a USDA-FS technical paper).

The original analysis which resulted in the carbon storage values used in both the first and second editions of *Solid Waste Management and Greenhouse Gases* was based on a hypothetical paper recycling program that started in 1995 and reached 55% recovery as of 2000 (in comparison to the baseline scenario of 50% recovery in 2000). In that analysis, we assumed that over the next 15 years, the recovery rates under both scenarios would continue to rise and would converge in the year 2016 at 57 percent. The resulting estimate, with 2010 chosen as the appropriate benchmark year, was **0.73 MTCE per short ton paper.** This analysis used the set of USDA-FS models that were initially developed to support forest resource planning and which were subsequently adapted to produce the estimates used in the national GHG inventory.

The analysis described here uses updated versions of several of those USDA-FS models of the U.S. forest sector to estimate the amount of forest carbon sequestration per incremental ton of paper reduced and recycled. These USDA-FS models and data sets are the most thoroughly documented and peer reviewed models available for characterizing and simulating the species composition, inventory, and growth of forests, and they have been used to analyze GHG mitigation

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[3] U.S. EPA. 2005. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*. U.S. Environmental Protection Agency, Office of Air and Radiation, Washington, DC. EPA-430-R-05-003.

[4] The forest carbon inventory in any year equals the carbon inventory the year before, plus net growth, less harvests, less decay. Thus, when harvests are reduced, the inventory increases. However when inventories become high relative to the carrying capacity of the land, the rate of growth decreases because net growth (the rate at which growth exceeds decay) declines.

[5] US EPA. 2002. Office of Solid Waste. EPA530-R-02-006. Washington, DC

in support of a variety of policy analyses conducted by the Forest Service, so they represent the current state-of-the-art.

We used an approach that modeled (1) the effect of incremental recycling on wood harvests, and (2) the change in forest carbon stocks as a function of marginal changes to harvest rates, using the FORCARB II model, and combined the two components to estimate the effect of recycling on forest carbon storage. We found that increased recycling of paper products resulted in incremental forest carbon storage of about 0.55 MTCE per short ton of paper recovered for mechanical pulp papers and 0.83 MTCE per short ton of paper recovered for chemical pulp papers.

The remainder of this memo is divided into five parts: Section 2 describes our approach to analyzing the effect of recovery on pulpwood harvest; Section 3 discusses the FORCARB II analysis; and Section 4 identifies the recommended value for use in the Climate & Waste Program and compares the results to those from other analyses. Section 5 then describes how we developed estimates of the effect of source reduction, and Section 6 describes sources of uncertainty.

2. Effect of Paper Recovery on Pulpwood Harvest

Several earlier USDA-FS efforts have analyzed the relationship between paper recovery rates and pulpwood harvests, based on data compiled by the American Forest and Paper Association (AFPA) and the Forest Resources Association (FRA). AFPA collects information on the mass of recovered paper and wood pulp consumed[6] and paper and paperboard production.[7] FRA publishes information on pulpwood receipts.[8] Using assumptions on the moisture content of pulpwood receipts (as harvested, 50%), paper and paperboard (3%), wood pulp consumed (10%), and recovered paper consumed (15%), Dr. Peter Ince of USDA-FS developed the following relationship:

$PWH = X * (PP – RPC*[1 – EX] * Y)$, where **(Eqn. 1)**

PWH = pulpwood harvests at 0% moisture content, i.e., ovendry (tons)
PP = paper production at 3% moisture content (tons)
RPC = Recovered paper consumption at 15% moisture content (tons)
EX = the proportion of recovered paper that is exported (%)
X = ratio of tons of ovendry pulpwood receipts per ton 3% moisture content of paper and paperboard . X accounts for the efficiency of converting to paper and paperboard and the portion of paper and paperboard that is water and fillers
Y = ratio of tons 15% moisture content of recovered paper consumed per ton 3% moisture content of paper and paperboard produced. Y accounts for the water in recovered paper and the efficiency of converting to paper and paperboard

Figure 1 shows the values of X, Y, RPC, and EX used for mechanical and chemical pulps.

The values of X and Y are based on process yield estimates provided by John Klungness (Research Chemical Engineer, USDA Forest Service) and Ken Skog (Project Leader, Timber Demand and Technology Assessment Research, USDA Forest Service). The value for EX, the

[6] AFPA. 2005. *Wood pulp, recovered paper, pulpwood 25th Annual survey, 2004-2007*. Washington, DC
[7] AFPA, 2004. *2004 Statistics - Paper, paperboard and wood pulp*. Washington, DC
[8] FRA, 2004. *Annual pulpwood statistics summary report, 1999-2003*. Rockville, MD

export rate, is based on examining total paper recovery and exports over the last 10 years for which data were available (1995-2004). Given that our focus is on the effect of small changes in paper recovery, it is more appropriate to focus on the marginal ratio of exports to paper recovery (rather than the average ratio). Thus, we calculated the change in annual exports for the end of the period compared to the beginning (3.23 million tons) and divided this figure by the change in annual paper recovery for the end of the period compared to the beginning (8.1 million tons), yielding a value of 40%. We used 40% as the export rate for both types of paper (mechanical and chemical).

Figure 1. Parameter Values for Equation 1.

Relationship between paper recovery and pulpwood harvest

	Average Yield, pulp: finished paper	**Average yield, recovered paper: finished paper**	**Marginal export rate**	**X (=1/avg yield, pulp: finished paper)**	**Y**	**Avoided PWH per tonne paper recovered**
Mechanical Pulp	90.0%	87.5%	40%	1.11	87.5%	0.58
Chemical Pulp	47.5%	70.0%	40%	2.11	70.0%	0.89

As shown in Exhibit 1, the avoided pulpwood harvest is 0.58 tonne per ton paper recovered for mechanical pulp papers, and 0.89 tonne per ton paper recovered for chemical pulp papers.

3. The Effect of Change in Pulpwood Harvest on Forest Carbon – FORCARB II Analysis

FORCARB II simulates the complex, dynamic nature of forest systems, including the interaction of various forest carbon pools, how carbon stocks in those pools change over time, and whether the response of forest carbon is linearly proportional to harvests. To explore these questions, USDA-FS ran the two enhanced recycling/reduced pulpwood harvest scenarios in FORCARB II. The base assumptions on pulpwood harvests are derived from NAPAP (North American Pulp and Paper) Model baseline projections developed for the Forest Service 2001 RPA Timber Assessment.[9] The two reduced harvest scenarios involved decreasing pulpwood harvest by 6.7 million tons and 20.2 million tons for the period 2005-2009. Harvests in all other periods were the same as the baseline.

For each scenario, we calculated the delta in carbon stocks with respect to the base case – this represents the carbon benefit of reduced harvests associated with recycling. We divided the change in carbon by the incremental tons of pulpwood harvested to yield results in units of MTCE per tonne pulpwood not harvested, i.e., the carbon storage rate.

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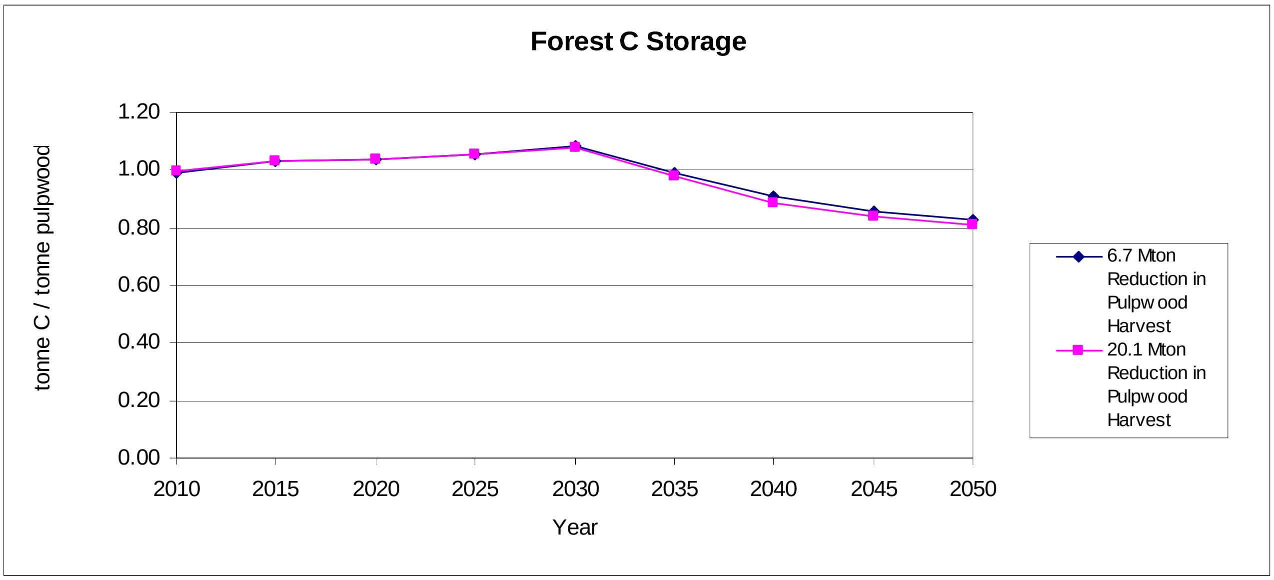
[9] Haynes, R.W. (Technical Coordinator). 2003. *An Analysis of the Timber Situation in the United States: 1952 to 2050*. General Technical Report PNW-GTR-560. http://www.fs.fed.us/pnw/pubs/gtr560/

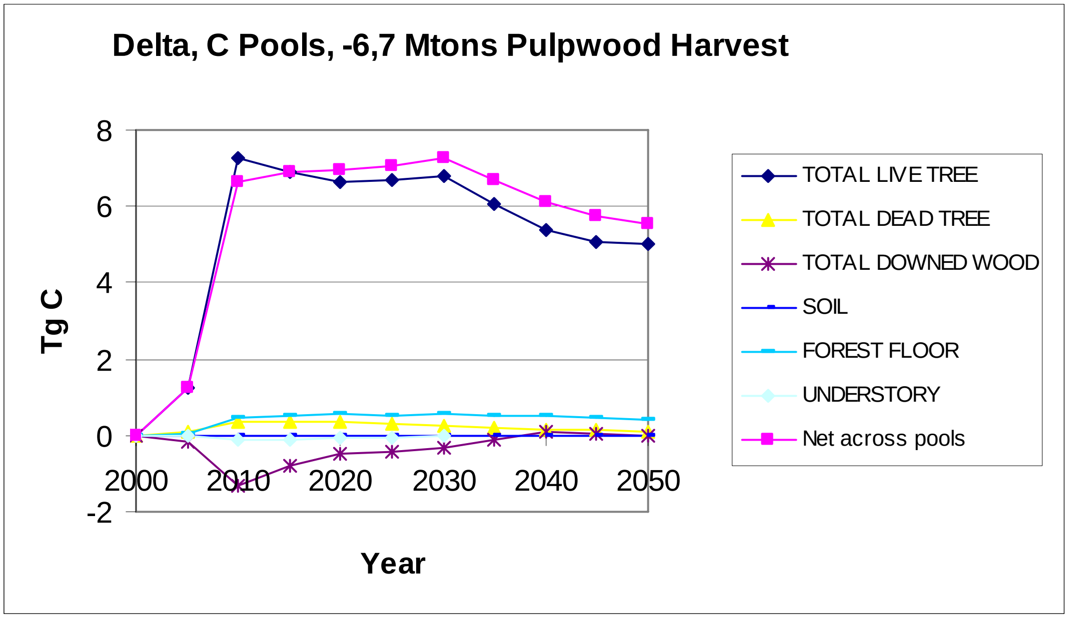
As shown in Exhibit 2, the carbon storage rate starts at about 0.99 MTCE per tonne pulpwood in 2010, increases to about 1.08 MTCE per tonne pulpwood in 2030, and declines with time to about 0.82 MTCE Carbon per tonne pulpwood in 2050. The exhibit also shows that across the two incremental recovery scenarios, the carbon storage rate (per unit paper recovered) was virtually identical.

Exhibit 2. Increased Forest Carbon Storage per Unit of Reduced Pulpwood Harvest



The use of the FORCARB II model allowed analysis of the timing and magnitude of changes in specific carbon pools within the forest. As shown in Exhibit 3, the primary effect of reduced pulpwood harvests was to increase the total live tree pool. This effect was offset to some degree by a decrease in the total downed wood pool. Carbon in the total dead tree, forest floor, and understory pools increased slightly; there was no effect on the soil pool. Most of the deltas peaked in 2010 and moderated somewhat over the next 40 years, though forest floor has more of a lag; the delta peaked in 2030. Both of those pools responded quickly to the change in harvests (which occurred for the 2005-2009 period). It appears that the major driver of the net carbon storage estimate is the time it took for the competing effects in the live tree and total downed wood pools to decline back to the baseline levels; since the total downed wood pool returns to baseline levels more quickly than the Live Tree pool, the net actually increased through 2030.

Exhibit 3. Change, with respect to baseline, in carbon stocks for FORCARB II pools



The FORCARB II results indicate that the effect of paper recycling on carbon storage appears to be persistent (i.e., lasting at least for several decades). We suggest using the value for 2020 for use in the Climate and Waste Program's emission factors, viz., **1.04 MTCE per tonne pulpwood**. The primary reason that 2020 would be appropriate is that it would represent a delay of about 5 to 15 years with respect to the onset of incremental recycling; this time lag is consistent with the lag chosen for the compost analysis used elsewhere in the emission factors. As shown above, the effect is relatively stable over time, so the choice of year does not have a significant effect.

4. Effect of Change in Paper Recovery on Forest Carbon

To estimate the rate of forest carbon change per ton of paper recovery, one can multiply the rate of pulpwood harvest (PWH) per ton of paper recovery (PRC) by the rate of forest carbon (FC) change per ton of pulpwood harvest, as shown below:

- For mechanical pulp,
  0.58 tonne PWH per tonne PRC * 1.04 tonne FC/tonne PWH = 0.61 tonne FC/tonne PRC
- For chemical pulp,
  0.89 tonne PWH per tonne PRC * 1.04 tonne FC/tonne PWH = 0.92 tonne FC/tonne PRC

Converting to rates of metric tones forest carbon per short ton of paper (to be consistent with units used throught the Climate and Waste Analysis), the values are 0.55 tonne FC/ton PRC and 0.83 tonne FC/ton PRC for mechanical and chemical pulps, respectively. We propose to assign the various paper grades in the Climate and Waste Analysis to mechanical or chemical pulp categories as follows:

- Mechanical pulp papers – newsprint, telephone books, magazines/third class mail
- Chemical pulp papers – office paper, corrugated cardboard, textbooks.

The following paragraphs compare these results to the previous estimate and to mass balance approaches, including one used for developing similar factors for Canada.

Comparison to the Original Estimate

The earlier value that we had derived (i.e., the value used in both the first and second editions of *Solid Waste Management and Greenhouse Gases*) was for a paper recycling program that started in 1995 and reached 55% recovery as of 2000 (in comparison to the baseline scenario of 50% recovery in 2000). We assumed that over the next 15 years, the recovery rates under both scenarios would continue to rise and would converge in the year 2016 at 57 percent. The resulting estimate, with 2010 chosen as the appropriate benchmark year, was **0.73 MTCE per short ton paper.**

However, in the original runs, we used the entire NAPAP/ TAMM/ ATLAS/ FORCARB/ WOODCARB set of models. As a result, there are several fundamental differences between those runs and the most recent ones:

- In the original runs, pulpwood harvests were actually projected to be *higher* between 2005 and 2010 under the high recycling scenario than in the baseline, due to price effects. Reduced pulpwood harvest before 2005 was simulated to result in increased supply of pulpwood ready for harvest in the 2005-2010 period, which reduced pulpwood prices, and led to modeled increases in industry demand for non-paper uses. The increased industry demand resulted in slightly higher pulpwood harvests after 2005. The current estimate does not reflect the cross-elasticity of demand between paper and non-paper products.
- In the original runs, this shift in products (from paper to non-paper) resulted in a change in carbon stocks in product pools. WOODCARB was used to simulate this effect, which reduced overall carbon storage in the product pool, especially in the early years of the scenarios.

Although we cannot determine the effect of the first factor, we can use data in the original report to recalculate the original forest carbon storage excluding the product-in-use pool, and the results are similar to the new ones (at least for 2010 and 2020): 1.22 MTCE per short ton paper in 2000; 0.91 MTCE per short ton paper in 2010; and 0.52 MTCE per short ton paper in 2020. The higher values in the previous version are likely a result of the lower rate of paper exports that prevailed at the time the model runs, and which were presumably assumed in the inputs. We believe that it is reasonable to assume that paper recovery does not result in a material change in the amount of carbon in the product-in-use pool.

Comparison with Canadian Mass Balance-derived Estimate

Another comparison of note is with a set of carbon storage factors developed for Environment Canada. These factors, which range from 0.76 to 1.13 MTCE per short ton paper, are based on comparing two sets of carbon efficiency estimates, shown in detail in Exhibit 4:

- Virgin pulp system efficiency, based on the mill input/forest cut ratio and mill carbon output/input ratio, and
- Recycled pulp system efficiency, based on the ratio of tonnes exiting the material recovery facility to tonnes of paper collected, and the mill carbon output/input ratio.

The recommended estimates (0.55 tonne FC/ton PRC and 0.83 tonne FC/ton PRC for mechanical and chemical pulps, respectively) are in the range of the Canadian estimates, which are based on a mass balance approach. The input / output relationships in the Canadian analysis (also performed by ICF) appear somewhat different from the system efficiencies used in this analysis, and the Canadian analysis did not consider exports at all, but nonetheless the results are similar, with the value for newsprint (0.60 tonne FC/ton PRC) quite close to the 0.55 tonne FC/tonne PRC mechanical pulp, and the values for fine paper, cardboard, and other paper a bit lower than the corresponding value for chemical pulp (0.83 tonne FC/ton PRC).

Exhibit 4. Mass Balance Calculations from Environment Canada Report

	Virgin Paper System Efficiency					Recycled Paper System Efficiency			Benefit of recycling, based on displacing 100% virgin paper
Paper Type	(a) Mill Input/Forest Cut Ratio	(b) Mill Carbon Output/Input Ratio	(c) Carbon retention (mill output: forest cut) (= a * b)	(d) C content of paper (wet wt)	**(e) Tonnes C not harvested per wet ton paper not made from 100% virgin inputs (= d / c)**	(f) Tonnes exiting MRF/tonnes collected	(g) Mill Carbon Output/Input Ratio	(h) Carbon retention (mill output/ paper collected) (=f * g)	**(i) Tonnes C/ ton paper recycled (= e * h)**
Newsprint	60%	90%	54%	45%	**0.76**	0.98	0.81	79%	**0.60**
Fine Paper	60%	60%	36%	45%	**1.13**	0.95	0.64	61%	**0.69**
Cardboard	60%	60%	36%	45%	**1.13**	0.98	0.69	68%	**0.77**
Other Paper	60%	60%	36%	45%	**1.13**	0.95	0.64	61%	**0.69**

5. Effect of Source Reduction on Carbon Stocks

We estimated source reduction values under two assumptions: that source reduction displaces only virgin inputs, and that it displaces the current mix of virgin and recycled inputs.[10] For the first assumption, 100% virgin, we used the process efficiency (X) values described in section 2 to calculate the amount of pulpwood harvest reduced per ton of paper source reduction. Those values are 1.11 tonne PWH/tonne and 2.11 tonne PWH/tonne for mechanical and chemical pulps, respectively (as shown in Exhibit 1). Multiplying these values by the rate of forest carbon storage per tonne of reduced PWH (1.04 MTCE/tonne PWH), and converting to short tons, source reduction of mechanical pulp papers manufactured from 100% virgin pulp would increase forest

[10] Source reduction may conceivably displace 100 percent virgin inputs if the quantity of paper recovered does not change with source reduction, and all recovered paper is used to make new paper. In that case, if the quantity of paper manufactured is reduced through source reduction, all of the reduction in inputs would come from virgin inputs. It is more likely, however, that source reduction reduces both virgin and recycled inputs. In fact, because source reduction would result in less used product being available to recover, it may have a greater effect on recovered fiber use than on virgin fiber. Thus, even the current mix scenario may represent the high end of the range of effects on forest carbon storage.

carbon storage by 1.04 MTCE/ton, and for chemical pulp papers, 1.98 MTCE/ton. These values are shown in Exhibit 5 in column (a).

Exhibit 5. Forest Carbon Effect of Source Reduction

Paper type	Mechanical (M) or Chemical (C)	Forest carbon benefit, MTCE/ ton 100% virgin paper source reduced (a)	% of Current Production from VIrgin Inputs (b)	Forest carbon benefit, MTCE/ ton "current mix" paper source reduced (c = a*b)
Corrugated Cardboard	C	1.98	65.1%	1.29
Magazines/Third-class Mail	M	1.04	95.9%	1.00
Newspaper	M	1.04	77.0%	0.80
Office Paper	C	1.98	95.9%	1.90
Phonebooks	M	1.04	100.0%	1.04
Textbooks	C	1.98	95.9%	1.90

The second scenario involves the assumption that source reduction would affect production using the current mix of virgin and recycled inputs. Given that displacing recycled inputs would not influence forest carbon per se, in this scenario the forest carbon effect is only attributable to the proportion of inputs that comprise virgin pulp, as shown in column (b) of Exhibit 5. The values in column (c) show the result of multiplying the virgin proportion in the current mix by the forest carbon benefit per ton of 100% virgin inputs.

6. Limitations and Uncertainty

There are several limitations associated with the analysis. The forest product market is very complex, and our simulation of some of the underlying economic relationships that affect the market simplifies some important interactions.

As noted earlier, the results are very sensitive to the assumption on paper exports (viz., that paper exports comprise a constant proportion of total paper recovery). If all of the recovered paper is exported, none of the incremental recovery results in a corresponding reduction in U.S. pulpwood harvest. At the other extreme, if all of the incremental recovery results in a corresponding reduction in U.S. pulpwood harvest, the storage factor would be higher. The results are also sensitive to assumptions on the moisture content and the carbon content of pulpwood, pulp, and paper.

Also, this analysis does not consider the effect that decreases in pulpwood harvest may have on the supply curve for sawtimber, which could result in a potential increase in harvests of other wood products. This could result in a smaller reduction in harvest, offsetting some of the carbon storage benefit estimated here. Prestamon and Wear[11] investigated how pulpwood and sawtimber supply would change with changes in prices for each. They estimated that non-industrial private forest and industry may increase sawtimber supply when price for pulpwood increases – and the change is perceived as temporary - although the estimate was not statistically

[11] J.P. Prestamon and D.N. Wear. 2000. *Linking Harvest Choices to Timber Supply*. Forest Science 46 (3): 377-389.

significant. But the sawtimber supply may decrease when pulpwood price increases – and the change is perceived as permanent – but once again the estimate was not statistically significant. Given that the relationship between the price change for pulpwood and supply of sawtimber were not consistent and were often statistically insignificant, we did not find compelling evidence to indicate that our omission of this effect is a significant limitation to the analysis.

A related issue is that if there is a decrease in the domestic harvest of pulpwood, it could result in a decrease in the cost of domestic production, which could shift the balance between domestic paper production and imports to meet demand.

Another limitation of our analysis is that we did not account for any potential long-term changes in land use due to a reduction in pulpwood demand, and landowners' choices to change land use from silviculture to other uses. If overall forest area is reduced, this would result in significant loss of carbon stocks. Hardie and Parks[12] developed an area base model for use in Resource Planning Act assessments to help determine factors that influence land area change. They derived a model that estimated the elasticity of forest land area change with respect to pulpwood price change. They estimated the elasticity to be -0.10 but this was not significant at the 10% confidence level. This suggests that forest area change would be limited with a modest price change in pulpwood demand.

In summary, there are several limitations and uncertainties associated with the analysis, but we believe that they are generally less significant compared to the uncertainty associated with the question of how much paper is exported. Despite the limitations and uncertainties, we believe that this analysis provides a reasonable approximation of the effects that increased paper recovery would have on forest carbon stocks, and that this analysis represents a significant step forward compared to the 1995 analysis.

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Wel look forward to your questions and comments on this memo.

[12] I.W. Hardie and P.J. Parks. 1997. *Land Use with Heterogeneous Land Quality: An Application of an Area Base Model.* American Journal of Agricultural Economics 79:299-310