Estimated Carbon Stored in Harvested Wood Products in Washington, USA: 1906 – 2018

Draft Report

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Executive summary and key findings

Forests assimilate carbon dioxide (CO_2) as trees grow, and over time some of the carbon acquired with growth may be stored in forest ecosystems as dead trees, downed woody material, or as soil organic matter. When carbon is removed from forests through timber harvest, a portion of the harvested carbon may be stored in the subsequent harvested wood products (HWP), often for many decades.

As part of a study authorized by the State of Washington, the Washington Department of National Resources (WA DNR) contracted with the United States (US) Department of Agriculture Forest Service Northern Research Station to compile estimates of HWP carbon using state-specific data within the Intergovernmental Panel on Climate Change (IPCC) Tier 3 production approach (IPCC 2006). For this assessment, a model conceived by Skog et al. (2008), adapted for state-level estimation (Stockmann et al. 2012) and recently modified by Groom Analytics, was adapted for use. This report provides resulting estimates of HWP carbon stocks and flux, or net annual change in stocks, over the interval from 1906 to 2018 for the state of Washington.

The model allocates carbon harvested and removed from Washington forest land as logs and allocates this to primary wood products according to distributions typical for the state. At the next level, primary products such as dimensional lumber, are allocated to end-use products, such as materials used in houses or wood pallets, which have very different lifespans. Disposal of the end-use products is tracked as a characteristic of each product and depends on their respective lifespans. Thus, HWP carbon storage in products can be short lived or persist in these end uses for a very long time. With disposal, there is further allocation of carbon, which can be emitted to the atmosphere through combustion or decay or discarded products can be placed in solid waste disposal sites (SWDS), such as landfills, for long-term storage without emission to the atmosphere.

The IPCC Tier 3 "production approach" focuses on accounting for carbon in all HWP that are produced in a particular state or country. In this application, all forest harvests in Washington are tracked through processing, use, and final disposition. For example, log exports from Washington are included in the accounting and tracked through final disposition, but imports to Washington from other states or countries, either as logs or wood products, are omitted under this accounting approach. The production approach contrasts with the stock change method, which measures all HWP consumed in the area regardless of origin, and the atmospheric flow method, which directly estimates annual atmospheric flux within domain boundaries. The production approach was selected for this analysis for Washington because it is the approach used by the Forest Service and US Environmental Protection Agency in United Nations Framework Convention on Climate Change reporting and is the same approach used in similar state-level analyses in Oregon and California.

Key findings

- Annual timber product output (TPO) has varied over the years where data are available (1906-2018) with the highest annual rates in the early 1970's and late 1980's, each over 10.6 million metric tons carbon (MMT carbon). Since the late 1980's, there has been a general decline, with 5.5 MMT carbon in 2017.
- Cumulative carbon stored in Washington harvested wood products (HWP) since 1906, including that currently in use or stored in SWDS, is approximately 350 MMT carbon.
- In 2018 (the last year of the study), the estimated HWP carbon stock is approximately 220 MMT carbon for products in use, 134 MMT carbon for products in SWDS, and 354 MMT carbon for the combined HWP pools.
- In 2018 the statewide rate of accumulation of carbon in HWP pools (in-use plus SWDS) was a net increase of approximately 7.5 MMT CO_2 equivalent (Eq.) per year. Of this flux, the increase in storage in solid waste disposal sites was 7.1 MMT CO_2 Eq. per year while the increase in the amount stored in products in-use was 0.4 MMT CO_2 Eq. per year.

Acknowledgements

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Background

Forest ecosystems are the largest terrestrial sink, or pool, of greenhouse gasses sequestered from the atmosphere, and annual net exchange with the atmosphere has consistently produced net atmospheric removals for US forest lands. Within the United States, the forest sector sequestered 752.9 million metric tons (MMT) CO_2 equivalent (Eq.) in 2018, which represented an offset of approximately 14 percent of total US greenhouse gas emissions (US EPA 2020). Of this, 564.5 MMT CO_2 Eq. accrued in forest ecosystems remaining as forest land and 98.8 MMT CO_2 Eq. was added to the harvested wood products (HWP) storage pools in the same year. Harvested wood products represent distinct pools of carbon removed from forests and sequestered in both long-lived and short-lived products (e.g., houses to newsprint, and including products sealed in long-term landfills; see US EPA 2020, Skog 2008, IPCC 2006, 2013, 2019, Smith et al. 2006).

Forest ecosystems in the State of Washington sequestered 23.3 MMT CO_2 Eq. 2018 (US EPA 2020, Domke et al 2020), which represents 4 percent of the estimate for the United States. The USDA Forest Service has been tasked by the Washington State Legislature through legislation passed in 2019 with conducting carbon inventories to build on existing efforts to understand carbon stocks, flux, trends, emissions, and sequestration across Washington's natural and working lands, including harvested wood products.

As defined by the Intergovernmental Panel on Climate Change (IPCC), HWP include primary products such as dimensional lumber, panels, paper, paperboard, and wood used for fuel or end use products such as houses or furniture (Skog 2008). Additions to the HWP pool are through harvesting and initial processing (largely at mills) while reductions are generally through emissions as a result of decay or combustion of wood products. Timing of emissions depends on length of time products remain in use. The HWP pool accounts for products both in-use as well as products that have been discarded to solid waste disposal systems (or sealed landfills), which limit emissions of these products (Skog 2008).

Approaches to estimating carbon in HWP have been developed for the national level (US EPA 2020, Skog 2008, IPCC 2006, 2013, 2019). National level approaches were slightly disaggregated to provide some regional resolution in Smith et al. (2006); however, these primarily rely on somewhat dated national level datasets. Accessible and practical tools for estimating and monitoring stocks and flux in HWP at the state level are needed (Ingerson 2011, Stockmann et al. 2012).

Stockmann et al. (2012) describe two methods to estimate HWP carbon for the US Forest Service Northern Region: the IPCC production approach (adopted by the US EPA), and the California Forest Project Protocol (CFPP). From this work, a model was created based upon the IPCC production approach using country-specific Tier 3 criteria data. At the request of the Washington Department of Natural Resources, the US Forest Service Northern Research Station, in coordination with scientists from the University of Montana's Bureau of Business and Economic Research and the US Forest Service Pacific Northwest Research Station, contracted to provide estimates of HWP carbon using state-specific data within the IPCC production approach method.

Objectives

Here we develop the means to quantify the contribution of HWP carbon as a contributing component of overall forest greenhouse gas mitigation resulting from Washington timber harvests. These estimates are compiled for the Washington Department of Natural Resources' carbon inventory. Our objectives are to:

1) Use the internationally established and accepted IPCC Tier 3 production approach to make estimates of HWP carbon stocks and net annual change (flux) for the state of Washington.
2) Provide a framework with clear metrics and estimation methods that can be applied to other land management units, such as by ownership or state sub-regions.

We have not developed a system nor estimates of carbon stored in HWP for evaluating the future impacts of specific management actions, nor do we advocate any particular course of action to improve carbon stewardship.

Washington forestland description

There are 22.5 million acres of forest land in Washington State; this is approximately half of the state's land area. Live trees comprise 853 MMT carbon (Palmer et al. 2019). The majority of forest biomass occurs on the moist west side of the state. These temperate rainforests contain some of the oldest and tallest trees in the country and store more aboveground biomass than most other forest ecosystems worldwide (Keith et al. 2009).

Most of the forest area includes conifer forest types (86 percent). Douglas-fir forest types are the most prevalent (40 percent of all forest land) followed by fir/spruce/mountain hemlock (17 percent) and hemlock/Sitka spruce (14 percent). Forests west of the Cascade Range crest are dominated by Douglas-fir, hemlock/Sitka spruce, and alder/maple types, while eastern Washington has considerable Douglas-fir and large areas of ponderosa pine forest types. Fir/spruce/mountain hemlock forests grow at high elevations and are evenly distributed between the east and west sides of the Cascade crest (Palmer et al. 2019).

The forest products industry is important within the state (Palmer et al. 2019). Forests are distributed among a variety of private forest owners and public land management agencies. Fifty-seven percent is publicly administered. Half of Washington's private forests are owned by corporations that tend to manage their land more intensively, with timber harvest as a primary objective.

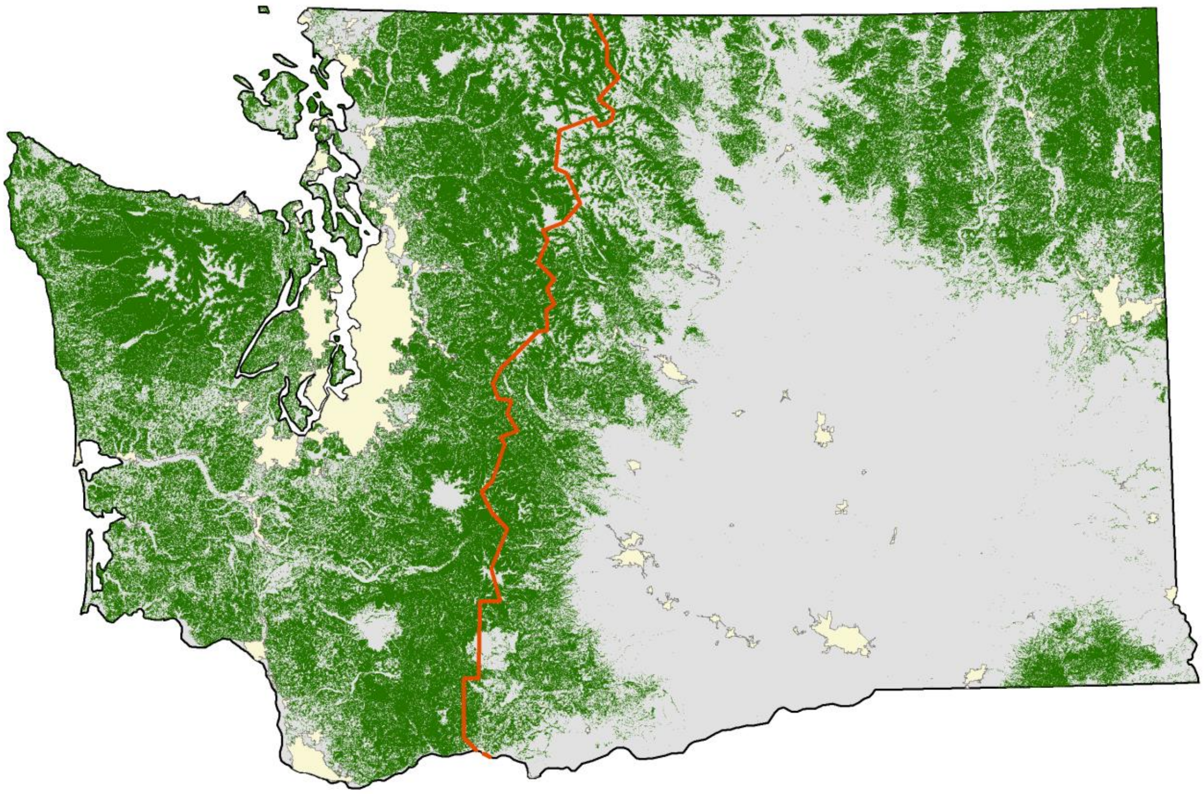

Figure 1. Washington forest land (green) and developed areas (yellow) from the 2016 National Land Cover Data image (Jin et al. 2019). The red line approximates the Cascade Range crest, which delineates west-side and east-side forest types within the state.

Methods

Harvested wood products are, in the simplest sense, products largely composed of wood. Also, in a very basic sense, these products provide prolonged storage of carbon and prevent or delay release of greenhouse gasses. Accounting for carbon in the myriad products, uses, lifespans, and destinations can be complex but important because the amount of this set-aside carbon can be considerable, considering single family residences and their contents alone. For this reason, HWP are a part of forest carbon accounting and greenhouse gas reporting.

As defined by the IPCC, HWP include primary products such as dimensional lumber, panels, paper, paperboard, and wood used for fuel or end use products such as houses or furniture (Skog 2008). Additions to the HWP pool are through harvesting and initial processing (largely at mills) while reductions are generally through emissions as a result of decay or combustion of wood products. Timing of emissions depends on the length of time products remain in use. The HWP pool accounts for products both in-use as well as products that have been discarded to solid waste disposal systems (SWDS). These sealed landfills considerably limit HWP emissions by limiting combustion or decomposition as compared with the more open to the atmosphere dumps, which were common disposal systems through most of the twentieth century (Skog 2008).

Here, we employ a simulation model that utilizes state specific data where possible to make the allocation of annual wood harvested to arrays of products with successive layers of secondary and end-use products, each characterized by different processing efficiencies, lifespans, and final disposition. Estimates are for the State of Washington.

Accounting for HWP with the production approach

We use the IPCC production approach, which has been adopted by the US Forest Service and the US EPA for national level reporting of carbon in HWP (US EPA 2020). The approach has been developed for state level reporting and is used here for HWP in Washington in order to conform to parallel reporting of other states and the entire United States.

In this IPCC production-based approach, the annual carbon stock change for the state's forest sector is a function of carbon flow among the atmosphere, forest ecosystems, and various HWP pools; and Washington forest growth and harvest – or, production – is key to defining model bounds. Growing trees absorb CO_2 from the atmosphere and incorporate the reduced carbon into a variety of molecular components; in this case, the organic carbon in wood is the focus here. Wood harvested from forests represents potential longer-term storage of carbon, while allowing forest regrowth with continued sequestration of carbon. This HWP storage produces an offset to greenhouse gas accumulation in the atmosphere (US EPA 2020).

The wood harvested from forests represents the production, which is subsequently tracked. The accounting follows carbon in all wood produced within the State of Washington; that is, harvested from Washington forests regardless of movement or subsequent form. Wood is processed into primary products, principally at mills, and these are ultimately transformed into a wide variety of end-use products (see appendix tables for examples of primary and end-use products explicitly considered by the model). Figure 2 illustrates the basic pathways for carbon to distinguish what is and what is not included in the production approach. Harvested wood in various forms can move in or out of the state, which makes the terms "export" and "import" important for tracking the carbon produced/harvested in the state. Exports out of the state are tracked and included. Imports into the state are not included in the accounting as they are considered a part of the production of their source of origin.

Two broadly collective pools of carbon in harvested wood are identified as products in-use and in very long-term storage after product disposal. This second stable pool is mostly carbon in SWDS. Some carbon is released during processing and is emitted to the atmosphere through combustion or decay (E_{WA} $E_{EX\ WA}$ in Figure 2). The same is true for a portion of end-use products in some instances of disposal. This re-emitted carbon from processing or disposal is tracked as associated with or without concomitant energy capture (Skog 2008).

Another important aspect of the production approach and the model used in this report is that stock and flux estimates in any given year are driven, in part, by the cumulative estimates from past decades. While quantities of HWP, their specific characteristics, and rates of change are likely to vary from one decade to another, some influences of these processes can affect estimates for subsequent years. The summed effects of a past year's additions and emissions are added to harvest and processing for each succeeding year. However, while HWP stock totals strongly reflect all past years that are included in the analysis, annual additions for a given year can have very little influence on annual net change after only a few years. See discussion of allocation to HWP pools as a function of year-since-harvest in Smith et al. (2006) and Skog (2008).

Note that the accounting presented here does not account for all emissions associated with HWP. For example, carbon emissions from fossil fuels used in harvest, transportation and manufacture of HWP are not addressed. Similarly, substitution of wood for fossil-fuel based materials is not addressed. Finally, only carbon as CO_2 absorption from or emission to the atmosphere is explicitly accounted for in the model.

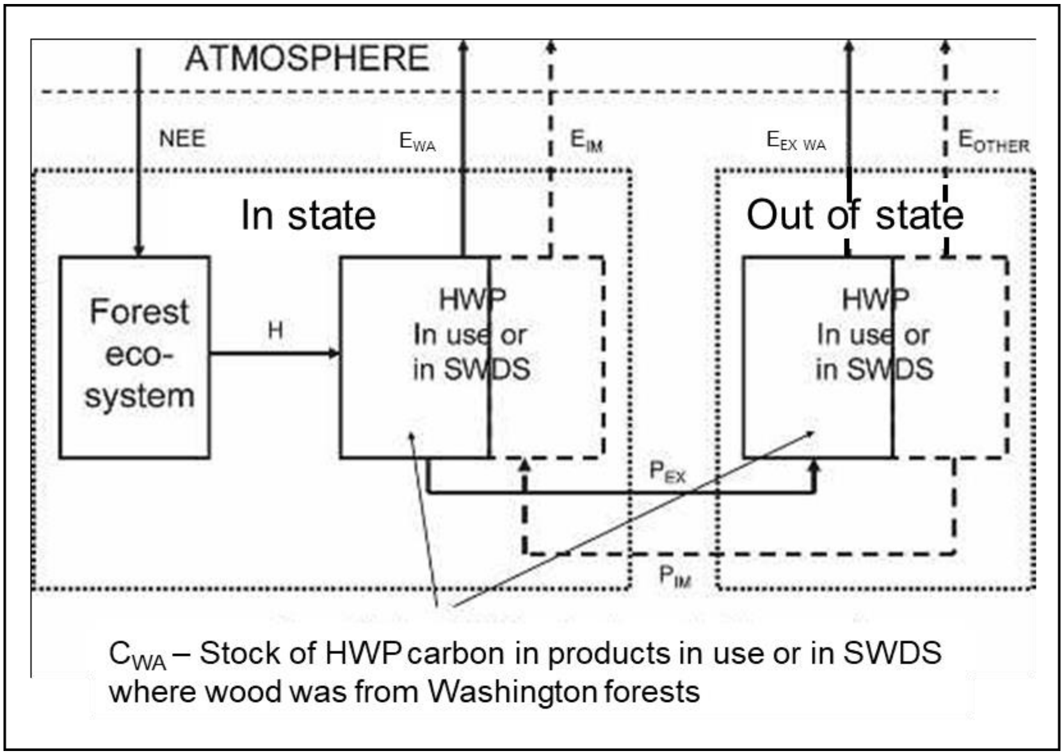

Figure 2. Carbon flows and stocks associated with forest ecosystems and harvested wood products (HWP) to illustrate the IPCC production (adapted from Skog 2008). See Table 1 for variable definitions.

Table 1. Fields used in modeling the HWP production approach (metric tons carbon per year). Based on Skog (2008) and Loeffler et al. (2019).

Field	Definition
ΔS	Annual carbon stock change, which is calculated as ΔS=(NEE-H)+(ΔC_{WA}) in the production accounting approach.
NEE	Annual net ecosystem carbon exchange, the annual net carbon that moves from the atmosphere to forests.
H	Annual harvest of wood for products, which includes wood and residues removed from harvest sites, but excludes resides left at harvest sites.
HWP	Harvested wood products in use or at solid waste disposal sites.
E_{WA}	Annual emission of carbon to the atmosphere in Washington from products made from wood harvested in Washington.
E_{IM}	Annual emission of carbon to the atmosphere in Washington from products made from wood harvested outside of Washington and imported into Washington.
P_{EX}	Annual exports of wood and paper products out of Washington, including roundwood, chips, residue, pulp and recovered (recycled) products.
P_{IM}	Annual imports of wood and paper products into Washington, including roundwood, chips, residue, pulp and recovered (recycled) products.
$E_{EX\ WA}$	Annual emission of carbon to the atmosphere in areas outside of Washington from products made from wood harvested in Washington.
E_{OTHER}	Annual emission of carbon to the atmosphere in areas outside of Washington from products made from wood harvested outside Washington.
C_{WA}	Stock of harvested wood products carbon in use or at solid waste disposal sites where products used wood from Washington.
$\Delta C_{IU\ WA}$	Annual change (flux) in carbon stored in harvested wood products in use where products

	used wood from Washington.
$\Delta C_{SWDS\ WA}$	Annual change (flux) in carbon stored in harvested wood products at solid waste disposal sites where products used wood from Washington.
ΔC_{WA}	Annual change (flux) in carbon stored in harvested wood products in use and at solid waste disposal sites where products used wood from Washington.

Model Computational Methods

Estimates of HWP carbon were calculated using a model based on the IPCC Tier 3 production approach. The current version of the model was developed in R by Jeremy Groom of Groom Analytics in coordination with Oregon State University as part of a similar study for the state of Oregon.

Two earlier versions of the model were developed by personnel from the US Forest Service, the University of Montana, the California Department of Forestry and Fire Protection, and Utah State University. The original version of the HWP carbon model referenced in Stockmann et al. (2012) requires two inputs: a harvest time series and a time series of timber product ratios that partition the harvest into different timber product classes. In addition, the user can further use state-specific primary product ratios or use regional values such as ones available in Smith et al. (2006). This allows the user to more accurately reflect state or regional differences in industry structure and primary product manufacturing.

The HWP model uses a series of calculations to estimate storage metrics for timber harvested in Washington. Figure 3 provides a flow chart of the sequence of computational methods used to calculate annual stock changes, and Table 1 identifies relevant fields within the model. This implementation of the IPCC production approach tracks carbon through the product life cycle from harvest to timber products to primary wood products to end use to disposal, applying best estimates for product ratios and half-lives at each stage.

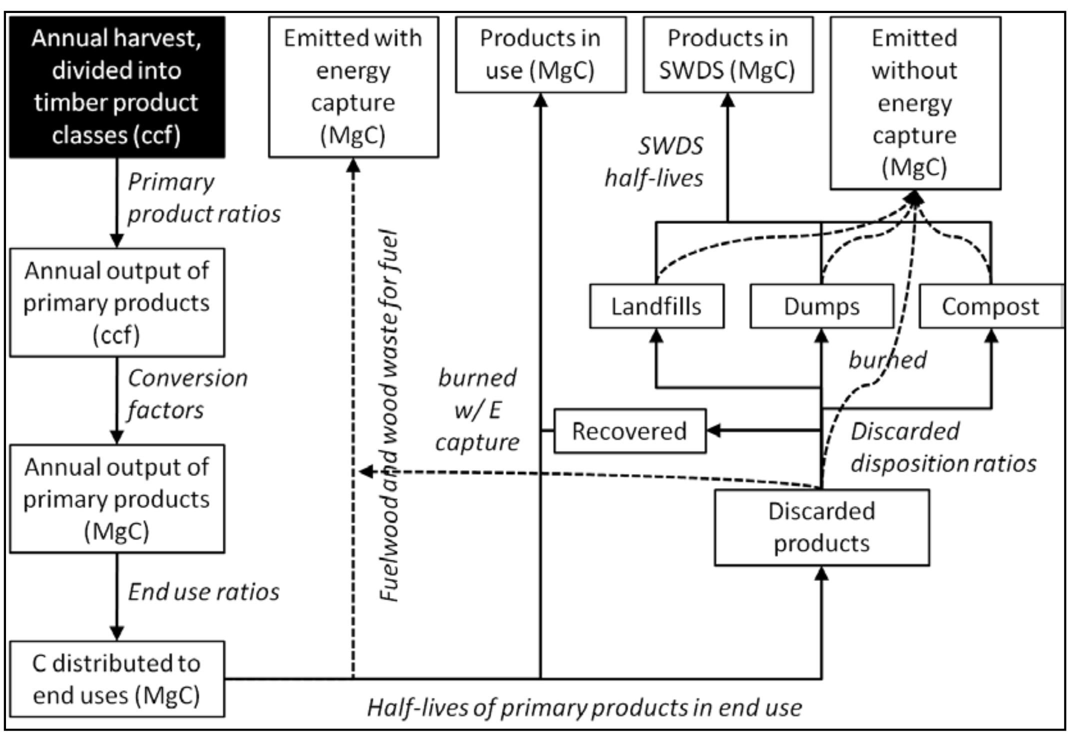

Figure 3. A schematic of HWP storage and emissions. The simulation model quantifies carbon in HWP products in-use, in SWDS, or emitted with- or without concomitant energy capture for the IPCC production approach. From Loeffler et al. (2019).

The current HWP carbon model variant, originally developed specifically for California, can now be applied to other states. The resulting model allows the user to enter any or all of eight additional model inputs or use the default values provided that were previously hardwired into the original model. The additional model variant inputs are:

1. Yearly end-use product ratios;
2. Products end-use half-lives;
3. Discarded products disposition ratios;
4. Discarded products disposition half-lives and landfill fixed ratios;
5. Distribution parameters;
6. Ratios for wood and paper burned with energy capture;
7. Thousand board feet (MBF) Scribner to hundred cubic feet (CCF) conversion factors;
8. Primary product CCF to metric tons carbon conversion factors.

Data Sources

Washington timber harvests are reported and publicly available for the years 1899 to the present (US Forest Service 2017). These reports and websites include volume of timber harvested in the state. Throughout the harvest record, data were available at the state level with no gaps in the harvest timeline. Results in this report were gathered from calendar year harvest reports from 2003 to the present and from the summary database for years from 1906 to 2002. See Appendix 1, Table 1 for harvest volume data for Washington and Table 2 for a summary of conversion factors applied to develop consistent estimates over time. The model estimates could be further disaggregated to substate forest owner categories if harvest data for all Washington ownerships were readily available prior to 1965 and between 2003 and 2012.

Timber harvest records are used to distribute annual cut timber volumes among specific timber product classes (e.g., softwood ties, softwood sawlogs, softwood pulpwood, softwood poles, softwood fuel wood, softwood non-saw, etc.) (Appendix 1 Table 1). This distribution results in a set of timber product ratios across each timber product class (Table 3, Appendix 1, Table 2). For periods of time when timber product ratios could not be determined, ratios available from a more recent time period were used. Following the same approach, timber products are further distributed to specific primary wood products resulting in primary product ratios (e.g. softwood lumber, softwood plywood, softwood mill residue used for non-structural panels, etc., Appendix 1, Table 3). Again, for periods of time when primary product ratios could not be determined, ratios available from a more recent time period were used.

Table 2. Conversion factors used in this analysis.

Conversion	Units
8.5960	board feet per cubic foot, timber harvest 1906 – 1910
8.1410	board feet per cubic foot, timber harvest 1911 – 1920
7.6923	board feet per cubic foot, timber harvest 1921 – 1930
7.2310	board feet per cubic foot, timber harvest 1931 – 1940
6.7760	board feet per cubic foot, timber harvest 1941 – 1950
6.3210	board feet per cubic foot, timber harvest 1951 – 1960
5.8660	board feet per cubic foot, timber harvest 1961 – 1970
5.4200	board feet per cubic foot, timber harvest 1971 – 1979
5.1700	board feet per cubic foot, timber harvest 1980 – 1989

4.5500	board feet per cubic foot, timber harvest 1990 – 1999
4.0674	board feet per cubic foot, timber harvest 2000 – 2003
4.1813	board feet per cubic foot, timber harvest 2004 – 2008
4.0161	board feet per cubic foot, timber harvest 2009 – 2018
33 to 42	pounds per cubic foot, primary products
2204.6	pounds per metric ton
0.95 to 1.0	metric ton wood fiber per metric ton product
0.5	metric ton carbon per metric ton dry wood fiber
0.71 to 0.91	metric ton carbon per hundred cubic feet primary products[1]

[1]See Appendix 1, Table 9 for CCF to MT C conversions for all primary products

Table 3. Average proportion of Washington harvests allocated to timber product classes from 1906 through 2018. That is, a summary of current model for Washington; averages reflect Appendix 1, Table 2.

Product class	Mean proportion of harvest
Sawtimber, hardwood	0.026
Sawtimber, softwood	0.809
Pulpwood, hardwood	0.014
Pulpwood, softwood	0.111
Poles, softwood	0.008
Softwood, miscellaneous converted	0.031

Uncertainty analysis

Because results of a simulation model are the product of the system (e.g., Washington forest sector), model assumptions, and input data, the interpretation of results partly depends on confidence in the parts. Although we identified and compiled available data with the goal of greatest accuracy possible, uncertainties exist. Conversion factors (which depend on log size, mill technology and efficiency, etc.), distribution of timber products to primary products, and the distribution of primary products to end uses have changed over time. There remains uncertainty in the use of data, and this uncertainty may increase with use of older data as well.

Uncertainty can be quantified through Monte Carlo simulations that employ probability distributions to define specific inputs of the model. See Appendix 1, Table 8 for additional detail on the list of distribution parameters as proposed for such an uncertainty analysis following methods described in Skog (2008). The Monte Carlo simulation is not implemented in the current model but is planned for future development.

Results

Total Washington timber harvest

Washington's timber harvest records, as board feet harvested, date back through 1906 (Table 4 and Appendix

1, Table 1). The relationship between the board foot scale and wood biomass has changed over the interval from 1906 through 2018. Using the conversion factors of Table 2, a consistent representation of the mass of carbon harvested for timber products is presented in Figure 4. Timber harvests in Washington have steadily increased over most of the 112-year interval, with three notable exceptions, which are 1929-1932; the mid-1970's to early 1980's; and late 1980's to 2009. A general increase in harvest characterizes most of the period since 2009. Recent harvests are generally between 5 and 6 MMT carbon.

Note that these values account for the merchantable part of trees harvested and removed from the site; that is, they do not include tops, cull trees or other biomass that remain on forest land.

Table 4. Annual timber harvest in Washington for selected years since 1906. Also see Figure 4 and Appendix 1, Table 1.

Harvest year	Harvest billion (10^9) board feet Scribner	Timber product output MMT carbon
1906	4.31	3.70
1916	4.49	4.07
1926	7.55	7.24
1936	4.57	4.67
1946	3.83	4.17
1956	5.04	5.88
1966	6.08	7.65
1976	6.97	9.50
1986	6.56	9.40
1996	4.37	7.17
2006	3.26	5.82
2007	3.25	5.77
2008	2.69	4.76
2009	2.07	3.82
2010	2.75	5.07
2011	3.01	5.56
2012	2.77	5.11
2013	3.33	6.14
2014	3.44	6.35
2015	3.03	5.60
2016	3.03	5.60
2017	3.00	5.53
2018	2.80	5.16

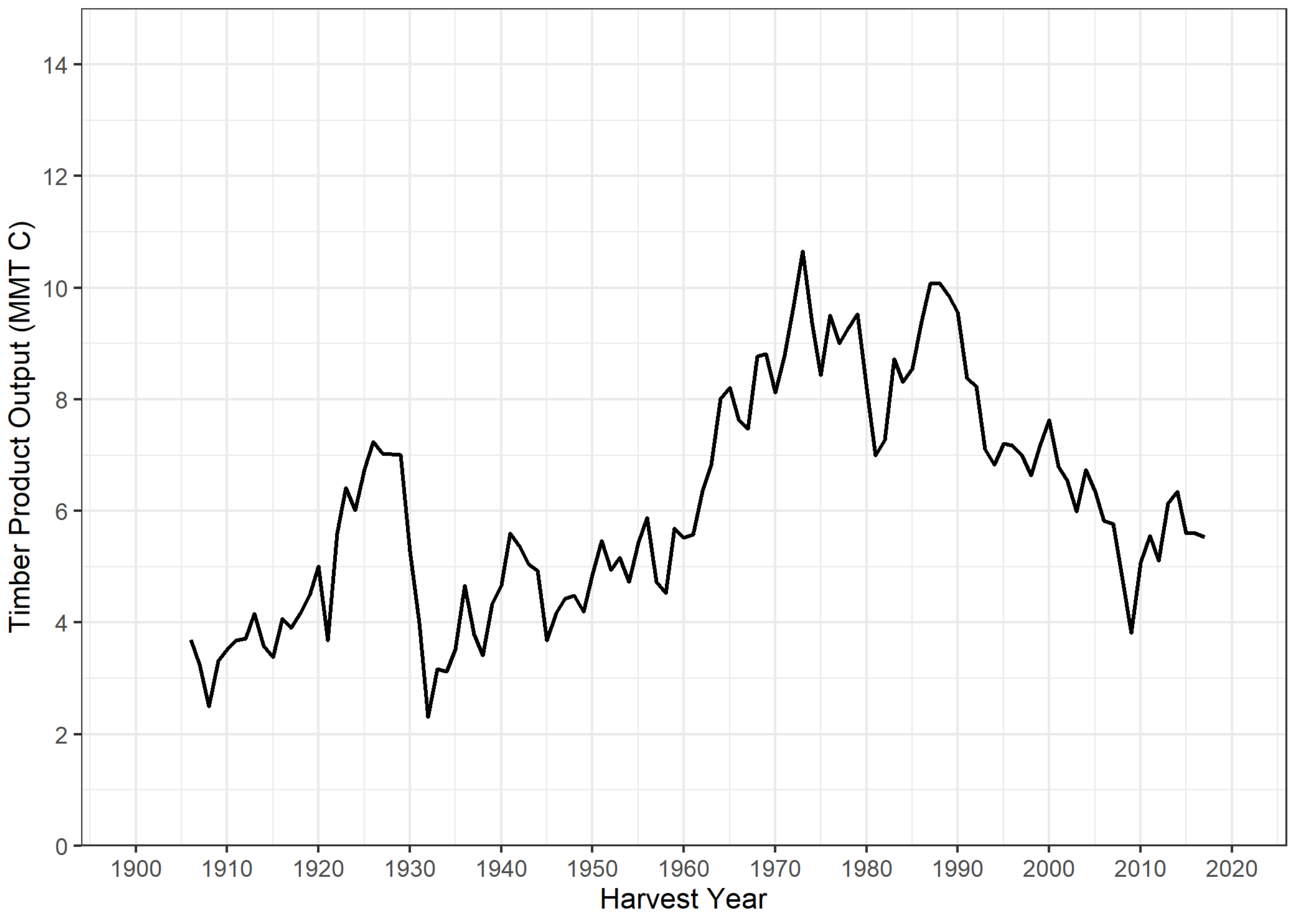

Figure 4. Annual timber product output in Washington, 1906-2018 (MMT carbon).

Total Washington HWP carbon stock and flux

The cumulative sum of carbon estimated to be in HWP and sequestered in products remaining in use or in SWDS is approximately 350 MMT carbon (Figure 5). This is based on the model starting point in 1906.

The various end-products that store carbon in HWP have very different controls affecting pool size, rates of accumulation, and lifespans (or rates and means of disposal). For this reason, cumulative summaries provide an effective summary measure of all processes. However, these cumulative totals are very dependent on the 'start date' such as 1906 for Figure 5. However, the simulation model that produced the estimates for Figure 5 can reset the starting year to any point over the interval. This is necessary if data from multiple states are combined to form regional estimates; data years common to all states can be used.

Note that the relative proportion of carbon in SWDS (Figure 5) increases notably after the 1970's, which is approximately the time when many dumps were replaced by sealed landfills, which retain significantly greater proportion of carbon in products.

Total cumulative fate of carbon in HWP, including emitted carbon, is provided for selected years in Table 5 and all years in Appendix 4. Carbon emitted from HWP with and without concomitant energy capture is provided as CO_2 equivalent to conform with most greenhouse gas emission reporting.

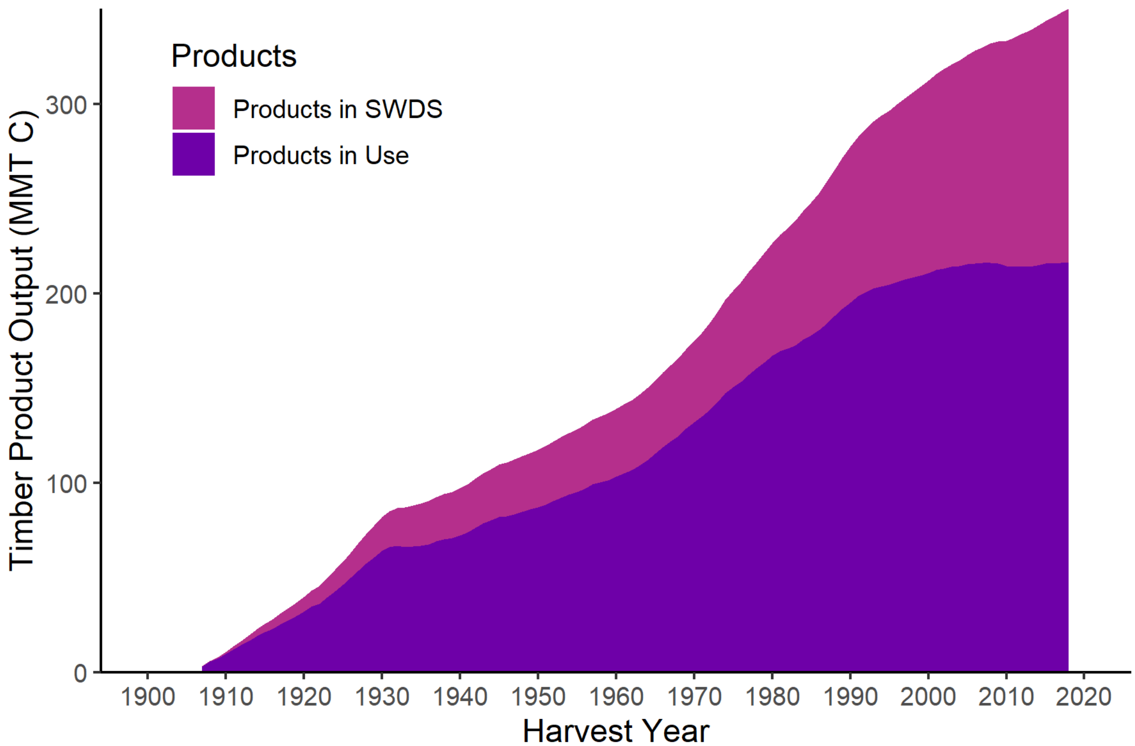

Figure 5. Cumulative total carbon stored in HWP manufactured from Washington timber using the IPCC production approach, 1906-2018. Carbon in HWP includes both products that are still in use and carbon stored at solid waste disposal sites (SWDS). Also see Table 5.

Table 5. Cumulative disposition of Washington HWP carbon for selected years using the IPCC production approach. This table shows the fate of all carbon removed from the ecosystem by harvesting. Also see Figure 5.

Inventory year	Emitted with energy capture (MMT CO_2 Eq.)	Emitted without energy capture (MMT CO_2 Eq.)	Harvested wood products in use (MMT carbon)	Products in solid waste disposal sites (MMT carbon)	Total of HWP not emitted (MMT carbon)
1910	4.73	2.20	9.65	1.22	10.88
1920	19.05	23.60	31.97	7.86	39.83
1930	41.92	71.78	64.32	17.88	82.21
1940	55.85	140.49	72.36	24.93	97.29
1950	73.10	220.08	87.08	30.40	117.47
1960	92.14	309.49	103.23	36.09	139.31
1970	119.56	416.32	132.94	42.97	175.91
1980	153.25	531.93	168.16	59.36	227.52
1990	184.16	632.94	196.55	82.44	279.00
2000	210.46	750.62	213.16	101.84	315.01
2001	213.17	762.54	215.09	103.56	318.65
2002	215.59	774.51	216.26	105.26	321.52
2003	217.92	786.32	217.18	107.04	324.22
2004	220.04	798.26	217.61	108.75	326.37
2005	222.44	810.19	218.70	110.50	329.20
2006	224.77	822.07	219.41	112.26	331.67
2007	226.91	833.88	219.67	114.02	333.68

2008	229.06	845.61	219.88	115.79	335.67
2009	230.83	857.21	219.24	117.54	336.78
2010	232.24	868.62	217.85	119.25	337.10
2011	234.12	879.91	217.60	120.98	338.58
2012	236.15	891.09	217.78	122.76	340.54
2013	238.00	902.14	217.59	124.54	342.13
2014	240.20	913.12	218.29	126.38	344.67
2015	242.47	924.06	219.14	128.28	347.42
2016	244.53	934.91	219.32	130.18	349.50
2017	246.59	945.71	219.49	132.10	351.59
2018	248.62	956.46	219.59	134.05	353.64

Annual net additions (or deletions) of carbon to HWP in-use or in SWDS are provided in Figure 6 and Table 6. Additions to carbon in SWDS exceed net additions of carbon to products in-use over most years and in particular, recent years.

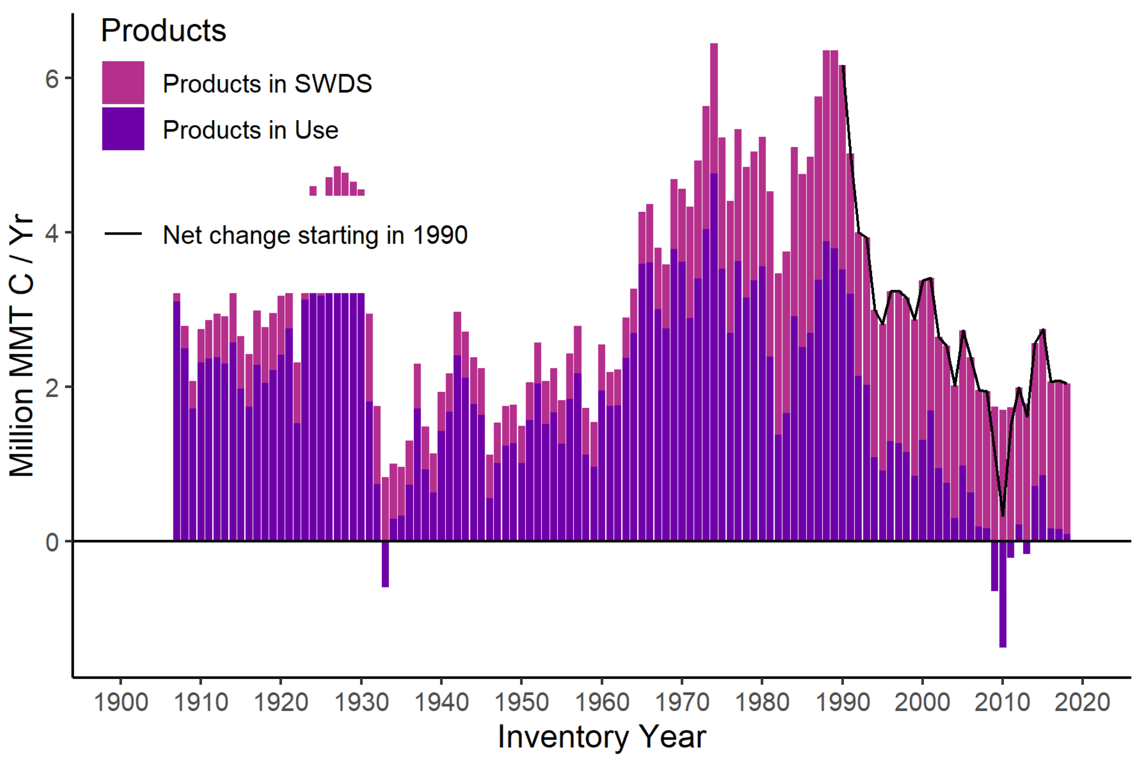

Figure 6. Annual flux, or net change, in carbon stocks for HWP in-use or in solid waste disposal sites for Washington according to the IPCC production approach (million metric tons carbon per year), 1906-2018. For this presentation, flux reflects stock differences between successive years so that negative values indicate a step decrease in the carbon pool, while positive values indicate an increase in pool size. This convention is used here for a more intuitive interpretation of the figure as 'net additions' but is the reverse of common reporting conventions (see US EPA 2020). The change trend line is the sum of change in both pools (in-use and SWDS).

Table 6. Selected net annual change (flux) in HWP stocks for products in-use, in SWDS, and the sum of both pools (MMT CO_2 Eq. per year). For this presentation, flux reflects stock differences between successive years so that negative values indicate a step decrease in the carbon pool, while positive values indicate an increase in pool size. This convention is used here to conform to Figure 6, which shows net annual additions, but is the reverse of common reporting conventions (see US EPA 2020).

Inventory year	Harvested wood products in use (MMT CO_2 Eq. / year)	Products in solid waste disposal sites (MMT CO_2 Eq. / year)	Total of HWP pools (MMT CO_2 Eq. / year)
1910	8.51	1.57	10.08
1920	8.85	2.81	11.66
1930	12.32	4.41	16.72
1940	5.23	1.86	7.09
1950	3.72	1.78	5.49
1960	7.16	2.18	9.34
1970	13.44	3.45	16.89
1980	13.06	6.14	19.20
1990	13.00	9.69	22.69
2000	4.82	7.57	12.39
2001	7.07	6.30	13.37
2002	4.29	6.23	10.53
2003	3.37	6.51	9.87
2004	1.59	6.29	7.88
2005	3.97	6.41	10.39
2006	2.62	6.44	9.05
2007	0.94	6.46	7.40
2008	0.76	6.50	7.27
2009	-2.31	6.41	4.10
2010	-5.10	6.26	1.16
2011	-0.94	6.36	5.42
2012	0.68	6.50	7.18
2013	-0.70	6.54	5.85
2014	2.56	6.76	9.32
2015	3.12	6.94	10.07
2016	0.64	6.97	7.61
2017	0.62	7.06	7.68
2018	0.39	7.12	7.51

The annual allocation of harvested carbon to more detailed categories for recent years is provided in Table 7. That is, these detail carbon remaining in end-use products, recovered products, landfills, or dumps. Similarly, carbon emitted with energy capture is classified as from fuelwood or discarded products. Carbon emitted without energy capture is identified as either decay from landfills, dumps, recovered products, or compost or simply from burning with no energy recovery. Note the increased storage in landfills along with the decrease in carbon in dumps over the interval from 1990 through 2018.

Table 7. Selected yearly carbon dispositions. These calculations quantify cumulative carbon storage from

HWP products in use and in SWDS, and cumulative emissions with and without energy capture using the IPCC production approach.

Disposition category	2018	2017	2010	2000	1990
Cumulative storage (MMT carbon)					
Products in use					
End-use products	216.24	216.14	214.39	210.71	195.44
Recovered products	3.35	3.34	3.46	2.45	1.12
Products in SWDS					
Carbon in landfills	122.68	120.32	103.93	78.98	47.30
Carbon in dumps	11.36	11.78	15.32	22.86	35.14
Cumulative emission (MMTCO_2 Eq.)					
Emissions w/ energy capture					
Emitted from fuelwood	248.62	246.59	232.24	210.46	184.16
Emitted from burning discarded products	0	0	0	0	0
Emissions w/o energy capture					
Emitted from landfills	68.74	66.55	51.55	31.09	14.52
Emitted from dumps	469.73	467.87	452.64	421.63	373.16
Emitted from recovered products	87.22	84.35	64.11	37.23	19.46
Emitted from burning	302.98	300.48	283.15	256.79	225.80
Emitted from compost	27.80	26.46	17.19	3.87	0

Discussion

To place the estimates provided here in a national context, the forest ecosystem carbon stocks for the United States in 2018 are reported as 55987 MMT carbon (US EPA 2020) and the corresponding stock for Washington forest ecosystems was 2700 MMT carbon (Domke et al. 2020). The net annual forest ecosystem carbon stock change for the United States was a gain in forest stocks of 564.5 MMT CO_2 Eq. per year, and the corresponding net annual gain for Washington forests was 23.3 MMT CO_2 Eq. in 2018 (Domke et al. 2020). Similarly, national level estimates for net annual gain of carbon in HWP pools for 2018 were 31.5, 67.2, and 98.8 MMT CO_2 Eq. for HWP in-use, in SWDS, and total HWP, respectively. The corresponding annual gains for HWP in Washington in 2018 were 0.39, 7.12, and 7.51 MMT CO_2 Eq. for HWP in-use, in SWDS, and total HWP, respectively. Note the year to year variability in recent years in annual flux for carbon in HWP, particularly carbon in HWP in-use (i.e., the lower rows in Table 6). This suggests that a multi-year interval of HWP estimates should be considered when determining the relative contribution of Washington HWP relative to the entire country. The 2018 estimates place the production approach gain in carbon in HWP in Washington as 7.6 percent of the United States' gain (US EPA 2020), and with a 5-year average, Washington represents 9.1 percent.

The success of this application of the IPCC production approach to model Washington, as well as California and Oregon, suggests that the process can be extended to other states. Data availability is expected to vary among states, so a number of such state-level applications can be useful in two ways. First, processing multiple states will provide an overview of the potentially different availabilities in compilations of source data among states, and this may help identify the more useful data sources for the model – based on accuracy or uncertainty analysis. Secondly, the expected, or potential, state-to-state variability in data sources also suggests that gaps in inputs might exist. Modeling many states may provide insights into means of addressing or filling such gaps should they exist. Could the addition of ancillary data predict or fill in gaps through the use of non-parametric regression or some other statistical approach? Many possibilities exist for future studies.

Uncertainty analysis should be developed for state level application. While placing confidence bounds around the simulated annual HWP increment is useful, the primary purpose of uncertainty analysis is for continued model development. That is, it can identify inputs that control both uncertainty and the deterministic result. Continuing model development focused on model elements identified through uncertainty analysis will have the greatest effect on improved predictions.

Conclusions

The production approach to HWP accounting applied to Washington identified a relatively large state-level flux relative to the national total. This is probably to be expected for states, such as Washington, that grow and provide a significant portion of the timber produced and incorporated into HWP. That is, alternate accounting approaches such as stock change or atmospheric flow would likely produce relatively different results for Washington relative to the entire country, but the production approach provides the most consistent predictions given current greenhouse gas reporting (US EPA 2020).

In conclusion, this model and the approach appear to be successful for estimating annual carbon in HWP for Washington. Continued model validation or application to other states can be useful to refine and build confidence in the results.

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Appendix 1

Table 1. Washington timber harvest data: 1906-2018 (Mbf = thousand board feet Scribner).

Year	Mbf	Year	Mbf	Year	Mbf
1906	4,305,000	1944	4,524,000	1982	5,079,064
1907	3,778,000	1945	3,384,000	1983	6,088,273
1908	2,916,000	1946	3,829,000	1984	5,801,972
1909	3,863,000	1947	4,068,000	1985	5,963,543
1910	4,097,000	1948	4,114,000	1986	6,555,957
1911	4,064,000	1949	3,850,528	1987	7,035,509
1912	4,100,000	1950	4,457,797	1988	7,045,372
1913	4,592,000	1951	4,677,903	1989	6,850,946
1914	3,946,000	1952	4,232,774	1990	5,849,227
1915	3,726,000	1953	4,419,481	1991	5,103,920
1916	4,493,000	1954	4,050,894	1992	5,017,676
1917	4,304,000	1955	4,650,600	1993	4,329,979
1918	4,602,000	1956	5,035,002	1994	4,155,930
1919	4,961,000	1957	4,045,901	1995	4,392,523
1920	5,525,000	1958	3,879,571	1996	4,366,287
1921	3,832,000	1959	4,868,810	1997	4,246,487
1922	5,835,000	1960	4,726,788	1998	4,021,572
1923	6,678,000	1961	4,435,728	1999	4,382,779
1924	6,267,000	1962	5,051,344	2000	4,176,568
1925	7,027,000	1963	5,427,711	2001	3,715,976
1926	7,546,000	1964	6,361,419	2002	3,582,070
1927	7,326,000	1965	6,521,775	2003	3,274,190
1928	7,305,000	1966	6,075,394	2004	3,789,576
1929	7,302,000	1967	5,936,417	2005	3,552,534
1930	5,502,000	1968	6,968,916	2006	3,260,417
1931	3,908,000	1969	7,003,817	2007	3,253,974
1932	2,261,000	1970	6,459,871	2008	2,688,569
1933	3,106,000	1971	6,450,530	2009	2,066,753
1934	3,064,000	1972	7,079,521	2010	2,746,773
1935	3,453,000	1973	7,809,396	2011	3,008,767
1936	4,572,000	1974	6,876,271	2012	2,769,078
1937	3,713,000	1975	6,185,051	2013	3,325,801
1938	3,349,000	1976	6,970,694	2014	3,438,774
1939	4,244,000	1977	6,590,985	2015	3,029,951
1940	4,574,000	1978	6,782,679	2016	3,031,713
1941	5,144,000	1979	6,969,265	2017	2,995,114
1942	4,929,000	1980	5,719,952	2018	2,803,991

1943	4,633,000	1981	4,890,898

Table 2. Washington timber product ratios.

WA_TimberProduct
Ratios

Table 3. Washington primary product ratios.

WA_PrimaryProduct
Ratios

Table 4. Washington end use product ratios.

WA_EndUseRatios

Table 5. Harvested wood product end-use half-lives.

WA_EndUseHalfLive
s

Table 6. Discarded product disposition ratios (embedded .pdf file).

WA_DiscardFates

Table 7. Discarded harvested wood and paper half-lives (years) and landfill fixed ratios.

Discard type	Landfill fixed ratio	Landfill half-life	Dump half-life	Recycled half- life
Paper	0.44	14.5	8.25	2.6
Wood	0.77	29	16.5	2.6

Table 8. Harvested wood products model parameters assigned as probabilistic inputs for a Monte Carlo simulation as an uncertainty analysis. All parameters are defined as triangular distributions. Note that the current HWP results are from the deterministic model only, these are included here as the proposed probabilistic inputs for future model development.

Parameter name	First year	Last year	Min. value	Peak value	Max. value
CCF to MT carbon conversion	n/a	n/a	0.95	1	1.05
Harvest	1906	1945	0.7	1	1.3
	1946	1979	0.8	1	1.2
	1980	2100	0.85	1	1.15

Timber product ratios	1906	1945	0.7	1	1.3
	1946	1979	0.8	1	1.2
	1980	2100	0.85	1	1.15
Primary product ratios	1906	1949	0.7	1	1.3
	1950	1979	0.8	1	1.2
	1980	2100	0.85	1	1.15
End use product ratios	n/a	n/a	0.85	1	1.15
Product half lives	n/a	n/a	0.85	1	1.15
Discard disposition ratios (paper)	n/a	n/a	0.85	1	1.15
Discard disposition ratios (wood)	n/a	n/a	0.85	1	1.15
Landfill decay limits (paper)	n/a	n/a	0.85	1	1.15
Landfill decay limits (wood)	n/a	n/a	0.85	1	1.15
Landfill half-lives (paper)	n/a	n/a	0.85	1	1.15

Table 9. Hundred cubic feet (ccf) to metric tons carbon conversion factors.

Primary product ID	Timber product	Primary product	Conversion factor
1	hardwood, sawtimber	fuelwood and other	0.91
2	hardwood, sawtimber	lumber	0.91
3	hardwood, sawtimber	non-structural panels	0.87
4	hardwood, sawtimber	oriented strandboard (OSB)	0.87
5	hardwood, sawtimber	other industrial products	0.91
6	hardwood, sawtimber	plywood	0.91
7	hardwood, sawtimber	wood pulp	0.91
8	softwood, sawtimber	fuelwood and other	0.74
9	softwood, sawtimber	lumber	0.74
10	softwood, sawtimber	non-structural panels	0.71
11	softwood, sawtimber	oriented strandboard (OSB)	0.87
12	softwood, sawtimber	other industrial products	0.74
13	softwood, sawtimber	plywood	0.75
14	softwood, sawtimber	wood pulp	0.74
15	hardwood, pulpwood	fuelwood and other	0.91
16	hardwood, pulpwood	lumber	0.91
17	hardwood, pulpwood	non-structural panels	0.91
18	hardwood, pulpwood	oriented strandboard (OSB)	0.87
19	hardwood, pulpwood	other industrial products	0.91

20	hardwood, pulpwood	plywood	0.91
21	hardwood, pulpwood	wood pulp	0.74
22	softwood, pulpwood	fuelwood and other	0.74
23	softwood, pulpwood	lumber	0.74
24	softwood, pulpwood	non-structural panels	0.71
25	softwood, pulpwood	oriented strandboard (OSB)	0.87
26	softwood, pulpwood	other industrial products	0.74
27	softwood, pulpwood	plywood	0.74
28	softwood, pulpwood	wood pulp	0.74
29	hardwood, poles	hardwood, poles	0.91
30	softwood, poles	softwood, poles	0.74
31	hardwood, pilings	hardwood, pilings	0.91
32	softwood, pilings	softwood, pilings	0.74
33	hardwood, mine props	hardwood, mine props	0.91
34	softwood, mine props	softwood, mine props	0.74
35	hardwood, posts	hardwood, posts	0.91
36	softwood, posts	softwood, posts	0.74
37	hardwood, fuelwood	hardwood, fuelwood	0.91
38	softwood, fuelwood	softwood, fuelwood	0.74
39	hardwood, non-sawtimber	hardwood, non-sawtimber	0.91
40	softwood, non-sawtimber	softwood, non-sawtimber	0.74
41	hardwood, ties	hardwood, ties	0.91
42	softwood, ties	softwood, ties	0.74
43	hardwood, coop bolts	hardwood, coop bolts	0.91
44	softwood, coop bolts	softwood, coop bolts	0.74
45	hardwood, acid/dist.	hardwood, acid/dist.	0.91
46	softwood, acid/dist.	softwood, acid/dist.	0.74
47	hardwood, float logs	hardwood, float logs	0.91
48	softwood, float logs	softwood, float logs	0.74
49	hardwood, trap float	hardwood, trap float	0.91
50	softwood, trap float	softwood, trap float	0.74
51	hardwood, misc-conv.	hardwood, misc-conv.	0.91
52	softwood, misc-conv.	softwood, misc-conv.	0.74
53	hardwood, nav stores	hardwood, nav stores	0.91
54	softwood, nav stores	softwood, nav stores	0.74

55	hardwood, cull logs	hardwood, cull logs	0.91
56	softwood, cull logs	softwood, cull logs	0.74
57	hardwood, sm rnd wd	hardwood, sm rnd wd	0.91
58	softwood, sm rnd wd	softwood, sm rnd wd	0.74
59	hardwood, grn bio cv	hardwood, grn bio cv	0.91
60	softwood, grn bio cv	softwood, grn bio cv	0.74
61	hardwood, dry bio cv	hardwood, dry bio cv	0.91
62	softwood, dry bio cv	softwood, dry bio cv	0.74
63	hardwood, sp wood pr	hardwood, sp wood pr	0.91
64	softwood, sp wood pr	softwood, sp wood pr	0.74

Appendix 2

Primary products associated with each timber product.

Timber Product ID	Timber Product	Primary Product ID	Primary Product
1	hardwood, sawtimber	1	fuelwood and other
1	hardwood, sawtimber	2	lumber
1	hardwood, sawtimber	3	non-structural panels
1	hardwood, sawtimber	4	oriented strandboard (OSB)
1	hardwood, sawtimber	5	other industrial products
1	hardwood, sawtimber	6	plywood
1	hardwood, sawtimber	7	wood pulp
2	softwood, sawtimber	8	fuelwood and other
2	softwood, sawtimber	9	lumber
2	softwood, sawtimber	10	non-structural panels
2	softwood, sawtimber	11	oriented strandboard (OSB)
2	softwood, sawtimber	12	other industrial products
2	softwood, sawtimber	13	plywood
2	softwood, sawtimber	14	wood pulp
3	hardwood, pulpwood	15	fuelwood and other
3	hardwood, pulpwood	16	lumber
3	hardwood, pulpwood	17	non-structural panels
3	hardwood, pulpwood	18	oriented strandboard (OSB)

3	hardwood, pulpwood	19	other industrial products
3	hardwood, pulpwood	20	plywood
3	hardwood, pulpwood	21	wood pulp
4	softwood, pulpwood	22	fuelwood and other
4	softwood, pulpwood	23	lumber
4	softwood, pulpwood	24	non-structural panels
4	softwood, pulpwood	25	oriented strandboard (OSB)
4	softwood, pulpwood	26	other industrial products
4	softwood, pulpwood	27	plywood
4	softwood, pulpwood	28	wood pulp
5	hardwood, poles	29	hardwood, poles
6	softwood, poles	30	softwood, poles
7	hardwood, pilings	31	hardwood, pilings
8	softwood, pilings	32	softwood, pilings
9	hardwood, mine props	33	hardwood, mine props
10	softwood, mine props	34	softwood, mine props
11	hardwood, posts	35	hardwood, posts
12	softwood, posts	36	softwood, posts
13	hardwood, fuelwood	37	hardwood, fuelwood
14	softwood, fuelwood	38	softwood, fuelwood
15	hardwood, non-sawtimber	39	hardwood, non-sawtimber
16	softwood, non-sawtimber	40	softwood, non-sawtimber
17	hardwood, ties	41	hardwood, ties
18	softwood, ties	42	softwood, ties
19	hardwood, coop bolts	43	hardwood, coop bolts
20	softwood, coop bolts	44	softwood, coop bolts
21	hardwood, acid/dist.	45	hardwood, acid/dist.
22	softwood, acid/dist.	46	softwood, acid/dist.
23	hardwood, float logs	47	hardwood, float logs
24	softwood, float logs	48	softwood, float logs
25	hardwood, trap float	49	hardwood, trap float
26	softwood, trap float	50	softwood, trap float
27	hardwood, misc-conv.	51	hardwood, misc-conv.
28	softwood, misc-conv.	52	softwood, misc-conv.
29	hardwood, nav stores	53	hardwood, nav stores
30	softwood, nav stores	54	softwood, nav stores
31	hardwood, cull logs	55	hardwood, cull logs
32	softwood, cull logs	56	softwood, cull logs
33	hardwood, sm rnd wd	57	hardwood, sm rnd wd
34	softwood, sm rnd wd	58	softwood, sm rnd wd
35	hardwood, grn bio cv	59	hardwood, grn bio cv
36	softwood, grn bio cv	60	softwood, grn bio cv
37	hardwood, dry bio cv	61	hardwood, dry bio cv
38	softwood, dry bio cv	62	softwood, dry bio cv

39	hardwood, sp wood pr	63	hardwood, sp wood pr
40	softwood, sp wood pr	64	softwood, sp wood pr

Appendix 3

End use products for each primary product.

Primary Product ID	Primary Product	End Use ID	End Use Product
1	fuelwood and other	1	fuelwood and other
2	lumber	2	manufacturing, other manufacturing
2	lumber	3	rail and railcar, n/a
2	lumber	4	packaging and shipping, n/a
2	lumber	5	manufacturing, furniture
2	lumber	6	other, n/a
2	lumber	7	new nonresidential, other
2	lumber	8	new nonresidential, new nonres buildings
2	lumber	9	residential r and r, n/a
2	lumber	10	new housing, manufactured housing
2	lumber	11	new housing, single family
2	lumber	12	new housing, multifamily
3	non-structural panels	13	manufacturing, other manufacturing
3	non-structural panels	14	new housing, multifamily
3	non-structural panels	15	new housing, single family
3	non-structural panels	16	residential r and r, n/a
3	non-structural panels	17	new nonresidential, new nonres buildings
3	non-structural panels	18	new nonresidential, other
3	non-structural panels	19	rail and railcar, n/a
3	non-structural panels	20	manufacturing, furniture
3	non-structural panels	21	new housing, manufactured housing
3	non-structural panels	22	packaging and shipping, n/a
3	non-structural panels	23	other, n/a
4	oriented strandboard (OSB)	24	new housing, multifamily
4	oriented strandboard (OSB)	25	rail and railcar, n/a
4	oriented strandboard (OSB)	26	new housing, single family
4	oriented strandboard (OSB)	27	new housing, manufactured housing
4	oriented strandboard (OSB)	28	manufacturing, furniture
4	oriented strandboard (OSB)	29	new nonresidential, new nonres buildings
4	oriented strandboard (OSB)	30	manufacturing, other manufacturing
4	oriented strandboard (OSB)	31	packaging and shipping, n/a
4	oriented strandboard (OSB)	32	other, n/a
4	oriented strandboard (OSB)	33	residential r and r, n/a
4	oriented strandboard (OSB)	34	new nonresidential, other
5	other industrial products	35	other industrial products
6	plywood	36	new housing, manufactured housing
6	plywood	37	new housing, multifamily
6	plywood	38	residential r and r, n/a

6	plywood	39	new nonresidential, new nonres buildings
6	plywood	40	new nonresidential, other
6	plywood	41	rail and railcar, n/a
6	plywood	42	manufacturing, furniture
6	plywood	43	manufacturing, other manufacturing
6	plywood	44	packaging and shipping, n/a
6	plywood	45	other, n/a
6	plywood	46	new housing, single family
7	wood pulp	47	wood pulp
8	fuelwood and other	48	fuelwood and other
9	lumber	49	residential r and r, n/a
9	lumber	50	packaging and shipping, n/a
9	lumber	51	manufacturing, other manufacturing
9	lumber	52	manufacturing, furniture
9	lumber	53	rail and railcar, n/a
9	lumber	54	new nonresidential, new nonres buildings
9	lumber	55	other, n/a
9	lumber	56	new housing, multifamily
9	lumber	57	new housing, manufactured housing
9	lumber	58	new housing, single family
9	lumber	59	new nonresidential, other
10	non-structural panels	60	manufacturing, other manufacturing
10	non-structural panels	61	other, n/a
10	non-structural panels	62	new housing, single family
10	non-structural panels	63	rail and railcar, n/a
10	non-structural panels	64	packaging and shipping, n/a
10	non-structural panels	65	new housing, manufactured housing
10	non-structural panels	66	residential r and r, n/a
10	non-structural panels	67	new nonresidential, other
10	non-structural panels	68	manufacturing, furniture
10	non-structural panels	69	new housing, multifamily
10	non-structural panels	70	new nonresidential, new nonres buildings
11	oriented strandboard (OSB)	71	rail and railcar, n/a
11	oriented strandboard (OSB)	72	new nonresidential, other
11	oriented strandboard (OSB)	73	new housing, manufactured housing
11	oriented strandboard (OSB)	74	residential r and r, n/a
11	oriented strandboard (OSB)	75	new nonresidential, new nonres buildings
11	oriented strandboard (OSB)	76	other, n/a
11	oriented strandboard (OSB)	77	packaging and shipping, n/a
11	oriented strandboard (OSB)	78	new housing, multifamily
11	oriented strandboard (OSB)	79	new housing, single family
11	oriented strandboard (OSB)	80	manufacturing, other manufacturing
11	oriented strandboard (OSB)	81	manufacturing, furniture
12	other industrial products	82	other industrial products
13	plywood	83	residential r and r, n/a
13	plywood	84	manufacturing, furniture
13	plywood	85	new housing, single family
13	plywood	86	new housing, multifamily
13	plywood	87	manufacturing, other manufacturing
13	plywood	88	other, n/a
13	plywood	89	rail and railcar, n/a
13	plywood	90	new nonresidential, new nonres buildings
13	plywood	91	new housing, manufactured housing
13	plywood	92	packaging and shipping, n/a
13	plywood	93	new nonresidential, other

14	wood pulp	94	wood pulp
15	fuelwood and other	95	fuelwood and other
16	lumber	96	rail and railcar, n/a
16	lumber	97	packaging and shipping, n/a
16	lumber	98	other, n/a
16	lumber	99	manufacturing, furniture
16	lumber	100	new housing, multifamily
16	lumber	101	new nonresidential, other
16	lumber	102	new housing, single family
16	lumber	103	new nonresidential, new nonres buildings
16	lumber	104	new housing, manufactured housing
16	lumber	105	residential r and r, n/a
16	lumber	106	manufacturing, other manufacturing
17	non-structural panels	107	manufacturing, other manufacturing
17	non-structural panels	108	new housing, multifamily
17	non-structural panels	109	other, n/a
17	non-structural panels	110	residential r and r, n/a
17	non-structural panels	111	new nonresidential, new nonres buildings
17	non-structural panels	112	packaging and shipping, n/a
17	non-structural panels	113	new nonresidential, other
17	non-structural panels	114	new housing, single family
17	non-structural panels	115	new housing, manufactured housing
17	non-structural panels	116	manufacturing, furniture
17	non-structural panels	117	rail and railcar, n/a
18	oriented strandboard (OSB)	118	manufacturing, other manufacturing
18	oriented strandboard (OSB)	119	packaging and shipping, n/a
18	oriented strandboard (OSB)	120	other, n/a
18	oriented strandboard (OSB)	121	manufacturing, furniture
18	oriented strandboard (OSB)	122	rail and railcar, n/a
18	oriented strandboard (OSB)	123	new nonresidential, new nonres buildings
18	oriented strandboard (OSB)	124	new housing, single family
18	oriented strandboard (OSB)	125	new housing, manufactured housing
18	oriented strandboard (OSB)	126	residential r and r, n/a
18	oriented strandboard (OSB)	127	new nonresidential, other
18	oriented strandboard (OSB)	128	new housing, multifamily
19	other industrial products	129	other industrial products
20	plywood	130	residential r and r, n/a
20	plywood	131	packaging and shipping, n/a
20	plywood	132	new housing, manufactured housing
20	plywood	133	new housing, single family
20	plywood	134	new housing, multifamily
20	plywood	135	other, n/a
20	plywood	136	manufacturing, other manufacturing
20	plywood	137	rail and railcar, n/a
20	plywood	138	new nonresidential, new nonres buildings
20	plywood	139	manufacturing, furniture
20	plywood	140	new nonresidential, other
21	wood pulp	141	wood pulp
22	fuelwood and other	142	fuelwood and other
23	lumber	143	residential r and r, n/a
23	lumber	144	manufacturing, furniture
23	lumber	145	new housing, manufactured housing
23	lumber	146	new housing, multifamily
23	lumber	147	new nonresidential, new nonres buildings
23	lumber	148	new nonresidential, other

23	lumber	149	manufacturing, other manufacturing
23	lumber	150	packaging and shipping, n/a
23	lumber	151	other, n/a
23	lumber	152	new housing, single family
23	lumber	153	rail and railcar, n/a
24	non-structural panels	154	new housing, single family
24	non-structural panels	155	manufacturing, furniture
24	non-structural panels	156	other, n/a
24	non-structural panels	157	packaging and shipping, n/a
24	non-structural panels	158	new nonresidential, new nonres buildings
24	non-structural panels	159	manufacturing, other manufacturing
24	non-structural panels	160	new nonresidential, other
24	non-structural panels	161	residential r and r, n/a
24	non-structural panels	162	new housing, multifamily
24	non-structural panels	163	rail and railcar, n/a
24	non-structural panels	164	new housing, manufactured housing
25	oriented strandboard (OSB)	165	manufacturing, furniture
25	oriented strandboard (OSB)	166	manufacturing, other manufacturing
25	oriented strandboard (OSB)	167	new nonresidential, other
25	oriented strandboard (OSB)	168	new housing, single family
25	oriented strandboard (OSB)	169	new housing, multifamily
25	oriented strandboard (OSB)	170	new housing, manufactured housing
25	oriented strandboard (OSB)	171	residential r and r, n/a
25	oriented strandboard (OSB)	172	rail and railcar, n/a
25	oriented strandboard (OSB)	173	packaging and shipping, n/a
25	oriented strandboard (OSB)	174	other, n/a
25	oriented strandboard (OSB)	175	new nonresidential, new nonres buildings
26	other industrial products	176	other industrial products
27	plywood	177	rail and railcar, n/a
27	plywood	178	new nonresidential, other
27	plywood	179	other, n/a
27	plywood	180	manufacturing, other manufacturing
27	plywood	181	new nonresidential, new nonres buildings
27	plywood	182	packaging and shipping, n/a
27	plywood	183	new housing, manufactured housing
27	plywood	184	new housing, multifamily
27	plywood	185	new housing, single family
27	plywood	186	manufacturing, furniture
27	plywood	187	residential r and r, n/a
28	wood pulp	188	wood pulp
29	hardwood, poles	189	hardwood, poles
30	softwood, poles	190	softwood, poles
31	hardwood, pilings	191	hardwood, pilings
32	softwood, pilings	192	softwood, pilings
33	hardwood, mine props	193	hardwood, mine props
34	softwood, mine props	194	softwood, mine props
35	hardwood, posts	195	hardwood, posts
36	softwood, posts	196	softwood, posts
37	hardwood, fuelwood	197	hardwood, fuelwood
38	softwood, fuelwood	198	softwood, fuelwood
39	hardwood, non-sawtimber	199	hardwood, non-sawtimber
40	softwood, non-sawtimber	200	softwood, non-sawtimber
41	hardwood, ties	201	hardwood, ties
42	softwood, ties	202	softwood, ties
43	hardwood, coop bolts	203	hardwood, coop bolts

44	softwood, coop bolts	204	softwood, coop bolts
45	hardwood, acid/dist.	205	hardwood, acid/dist.
46	softwood, acid/dist.	206	softwood, acid/dist.
47	hardwood, float logs	207	hardwood, float logs
48	softwood, float logs	208	softwood, float logs
49	hardwood, trap float	209	hardwood, trap float
50	softwood, trap float	210	softwood, trap float
51	hardwood, misc-conv.	211	hardwood, misc-conv.
52	softwood, misc-conv.	212	softwood, misc-conv.
53	hardwood, nav stores	213	hardwood, nav stores
54	softwood, nav stores	214	softwood, nav stores
55	hardwood, cull logs	215	hardwood, cull logs
56	softwood, cull logs	216	softwood, cull logs
57	hardwood, sm rnd wd	217	hardwood, sm rnd wd
58	softwood, sm rnd wd	218	softwood, sm rnd wd
59	hardwood, grn bio cv	219	hardwood, grn bio cv
60	softwood, grn bio cv	220	softwood, grn bio cv
61	hardwood, dry bio cv	221	hardwood, dry bio cv
62	softwood, dry bio cv	222	softwood, dry bio cv
63	hardwood, sp wood pr	223	hardwood, sp wood pr
64	softwood, sp wood pr	224	softwood, sp wood pr

Appendix 4

Cumulative disposition of Washington HWP carbon using the IPCC production approach. This table follows Table 6 and shows the fate of all carbon removed from the ecosystem by harvesting for all years available.

Inventory year	Emitted with energy capture (MMT CO_2 Eq.)	Emitted without energy capture (MMT CO_2 Eq.)	Harvested wood products in use (MMT carbon)	Products in solid waste disposal sites (MMT carbon)	Total of HWP not emitted (MMT carbon)
1907	1.37	0.23	3.11	0.16	3.26
1908	2.57	0.70	5.61	0.44	6.05
1909	3.50	1.34	7.33	0.79	8.13
1910	4.73	2.20	9.65	1.22	10.88
1911	6.03	3.29	12.02	1.72	13.74
1912	7.39	4.63	14.41	2.28	16.69
1913	8.77	6.20	16.71	2.90	19.61
1914	10.31	8.03	19.29	3.56	22.85
1915	11.64	10.08	21.26	4.25	25.51
1916	12.89	12.33	23.01	4.93	27.93
1917	14.40	14.81	25.29	5.63	30.92
1918	15.84	17.51	27.34	6.35	33.69
1919	17.39	20.43	29.56	7.09	36.65
1920	19.05	23.60	31.97	7.86	39.83
1921	20.91	27.04	34.73	8.67	43.40
1922	22.27	30.67	36.26	9.46	45.71
1923	24.34	34.58	39.39	10.29	49.68
1924	26.72	38.84	43.07	11.22	54.28
1925	28.95	43.42	46.25	12.19	58.44
1926	31.44	48.36	49.93	13.23	63.16
1927	34.12	53.68	53.88	14.34	68.22
1928	36.73	59.37	57.49	15.50	72.99

1929	39.32	65.41	60.97	16.68	77.65
1930	41.92	71.78	64.32	17.88	82.21
1931	43.87	78.39	66.13	19.02	85.15
1932	45.35	85.11	66.87	20.04	86.91
1933	46.21	91.83	66.28	20.87	87.15
1934	47.38	98.58	66.58	21.58	88.16
1935	48.54	105.37	66.91	22.21	89.12
1936	49.84	112.20	67.65	22.78	90.43
1937	51.57	119.17	69.37	23.36	92.73
1938	52.98	126.21	70.30	23.92	94.21
1939	54.24	133.30	70.93	24.43	95.35
1940	55.85	140.49	72.36	24.93	97.29
1941	57.58	147.90	74.03	25.43	99.47
1942	59.65	155.48	76.45	25.99	102.44
1943	61.64	163.23	78.56	26.59	105.15
1944	63.51	171.12	80.34	27.20	107.54
1945	65.33	179.12	81.97	27.82	109.79
1946	66.70	187.17	82.54	28.37	110.91
1947	68.24	195.28	83.55	28.90	112.45
1948	69.89	203.47	84.79	29.41	114.20
1949	71.55	211.75	86.06	29.91	115.97
1950	73.10	220.08	87.08	30.40	117.47
1951	74.90	228.52	88.65	30.89	119.54
1952	76.92	237.09	90.69	31.42	122.11
1953	78.75	245.77	92.22	31.97	124.19
1954	80.66	254.56	93.89	32.54	126.43
1955	82.41	263.44	95.16	33.11	128.27
1956	84.43	272.43	97.00	33.70	130.70
1957	86.60	281.58	99.18	34.31	133.49
1958	88.35	290.80	100.31	34.92	135.22
1959	90.03	300.08	101.27	35.49	136.77
1960	92.14	309.49	103.23	36.09	139.31
1961	94.18	319.14	105.12	36.53	141.65
1962	96.25	328.97	106.99	36.99	143.99
1963	98.60	339.00	109.46	37.51	146.97
1964	101.13	349.24	112.23	38.09	150.31
1965	104.10	359.77	115.89	38.75	154.64
1966	107.14	370.58	119.56	39.51	159.07
1967	109.97	381.64	122.63	40.30	162.93
1968	112.73	392.92	125.44	41.13	166.57
1969	115.98	404.49	129.27	42.03	171.30
1970	119.56	416.32	132.94	42.97	175.91
1971	122.87	426.83	135.85	44.41	180.27
1972	126.18	437.61	139.28	45.94	185.22
1973	129.82	448.62	143.35	47.52	190.87
1974	133.83	459.92	148.14	49.20	197.35
1975	137.37	471.46	151.70	50.91	202.61
1976	140.28	483.21	154.43	52.61	207.04
1977	143.57	495.17	158.06	54.33	212.39
1978	146.71	507.27	161.22	56.02	217.24
1979	149.93	519.53	164.60	57.69	222.28
1980	153.25	531.93	168.16	59.36	227.52
1981	156.10	542.22	170.63	61.50	232.13
1982	158.62	552.46	172.06	63.59	235.65
1983	161.23	562.64	173.74	65.69	239.43
1984	164.30	572.78	176.67	67.88	244.55
1985	167.23	582.87	179.20	70.12	249.31
1986	170.24	592.90	181.90	72.40	254.30
1987	173.56	602.91	185.30	74.76	260.06
1988	177.15	612.91	189.20	77.23	266.43
1989	180.74	622.92	193.01	79.80	272.81

1990	184.16	632.94	196.55	82.44	279.00
1991	187.47	644.78	200.16	84.26	284.42
1992	190.42	656.75	202.61	86.12	288.73
1993	193.32	668.79	204.86	88.03	292.88
1994	195.80	680.79	206.11	89.93	296.04
1995	198.19	692.71	207.12	91.84	298.96
1996	200.70	704.54	208.49	93.78	302.27
1997	203.20	716.25	209.80	95.75	305.56
1998	205.62	727.84	210.98	97.76	308.74
1999	207.91	739.30	211.85	99.78	311.63
2000	210.46	750.62	213.16	101.84	315.01
2001	213.17	762.54	215.09	103.56	318.65
2002	215.59	774.51	216.26	105.26	321.52
2003	217.92	786.32	217.18	107.04	324.22
2004	220.04	798.26	217.61	108.75	326.37
2005	222.44	810.19	218.70	110.50	329.20
2006	224.77	822.07	219.41	112.26	331.67
2007	226.91	833.88	219.67	114.02	333.68
2008	229.06	845.61	219.88	115.79	335.67
2009	230.83	857.21	219.24	117.54	336.78
2010	232.24	868.62	217.85	119.25	337.10
2011	234.12	879.91	217.60	120.98	338.58
2012	236.15	891.09	217.78	122.76	340.54
2013	238.00	902.14	217.59	124.54	342.13
2014	240.20	913.12	218.29	126.38	344.67
2015	242.47	924.06	219.14	128.28	347.42
2016	244.53	934.91	219.32	130.18	349.50
2017	246.59	945.71	219.49	132.10	351.59
2018	248.62	956.46	219.59	134.05	353.64