Appendix 21A Greenhouse Gas Support Appendix

21A.1 Introduction

This appendix documents the change in greenhouse gas (GHG) emissions due to changing the land use from open fields to the proposed reservoir located in Sites, California (the Sites Reservoir Project [Project]).

The GHG emissions presented in this appendix do not account for activities that would potentially sequester carbon, such as activities associated with Project implementation, or implementation of Project mitigation measures. The analysis represents a conservative assessment of emissions because it does not currently account for potential carbon sequestration activities that would result from the Project, such as offsite Project activities and Project features, or mitigation measures identified for other resource areas that may affect land use changes. Readers should note these considerations when reviewing this appendix and the emissions values and be aware that it is not possible at this time to provide a comprehensive accounting of emissions sources and sinks affecting land use–related emissions. As such, the focus of this appendix is on the net increase in emissions resulting from the change in land use in the inundation area, but there are other activities, features, and/or mitigation measures that may result in an emissions benefit but are not currently accounted for.

21A.2 Reservoir Greenhouse Gas Emissions

The Intergovernmental Panel on Climate Change (IPCC) has established guidelines for estimating GHG emissions (IPCC Guidelines) (Intergovernmental Panel on Climate Change 2019). In Chapter 7 of the IPCC Guidelines, reservoirs are identified as flooded lands when analyzing GHG emissions, with focus on carbon dioxide (CO_2) and methane (CH_4) emissions.

Per the IPCC Guidelines, "flooded land is exposed to natural or anthropogenic regulation of water levels, creating a drawdown zone. Greenhouse gas emissions from the drawdown zones are considered significant and similar per unit area to the emissions from the water surface (e.g., Yang et al. 2012 and Deshmukh et al. 2018) and are therefore included when estimating greenhouse gas emissions from Flooded Land."

The IPCC Guidelines classify reservoirs into two categories according to the length of time they have been flooded:

1. **Flooded Land Remaining Flooded Land**—Includes reservoirs that were converted to flooded land more than 20 years ago. Reservoirs in this category are analyzed for CH_4 emissions only.

2. **Land Converted to Flooded Land**—Includes reservoirs that were flooded less than or equal to 20 years ago. Reservoirs in this category are analyzed for both CH_4 and CO_2 emissions.

21A.2.1 Flooded Lands Remaining Flooded Lands Greenhouse Gas Emissions

The IPCC Guidelines identify CO_2 emissions for flooded land remaining flooded land: "The initial flooding of land can cause elevated CO_2 emissions as inundated soil and biomass decay. After this initial phase, typically lasting 20 years or less, the CO_2 emitted from Flooded Land is largely derived from carbon (C) input from the catchment, which is estimated as emissions from other managed land categories." The other land categories are considered part of the No Project Alternative and will not be addressed in this analysis. Therefore, CO_2 emissions at Sites Reservoir after 20 years are not presented.

For the analysis of flooded land remaining flooded land, total diffusive, ebullitive, and downstream CH_4 emissions can be analyzed using methods obtained through increasingly more detailed means or tiers. There are three tiers to estimate CH_4 emissions based on the information available. The Tier 1 approach uses equations and emission factors supplied in the IPCC Guidelines, using default equation constants where appropriate to account for any lack of data. Tier 2 uses the same equations and emission factors with more refined equation constants based on anticipated withdrawal depths and trophic levels, discussed further below. The Tier 3 approach uses direct measurements of CH_4 diffusion and ebullition fluxes across the reservoir surface. Since measurements of Sites Reservoir are not available at this time, the Tier 3 approach cannot be implemented.

Using the Tier 1 and 2 equations, annual total CH_4 emissions for reservoirs more than 20 years old can be estimated using the following equation (Intergovernmental Panel on Climate Change 2019:Equation 7.10):

$$F_{CH4tot} = F_{CH4res} + F_{CH4downstream}$$

$$F_{CH4res} = \alpha\ (EF_{CH4\ age>20,j} * A_{tot\ j})$$

$$F_{CH4downstream} = \alpha\ (EF_{CH4\ age>20,j} * A_{tot\ j}) * R_d$$

where

F_{CH4tot} = Total annual emission of CH_4, kilograms (kg) CH_4/year (yr)

F_{CH4res} = Annual reservoir surface emissions of CH_4, kg CH_4/yr

$F_{CH4downstream}$ = Annual emissions of CH_4 emitted downstream of dam, kg CH_4/yr

$A_{tot\ j}$ = Total area of reservoir water surface located in climate zone *j*, hectare (ha)

$EF_{CH4\ age>20,j}$ = Emission factor for CH_4 emitted from the reservoir surface for reservoir >20 years old located in climate zone *j*, kg CH_4/ha-yr

R_d = A constant equal to the ratio of total downstream emission of CH_4 to the total flux of CH_4 from the reservoir surface [dimensionless]. It is 0.09 by default for Tier 1.

α = Emission factor adjustment for trophic state in reservoir *i* within a given climate zone [dimensionless]. It is 1.0 by default for Tier 1.

Additionally, the equation for scaling CH_4 emission factors for eutrophication is estimated using the following equation (Intergovernmental Panel on Climate Change 2019:Equation 7.11):

$$\alpha = 0.26 * Chla$$

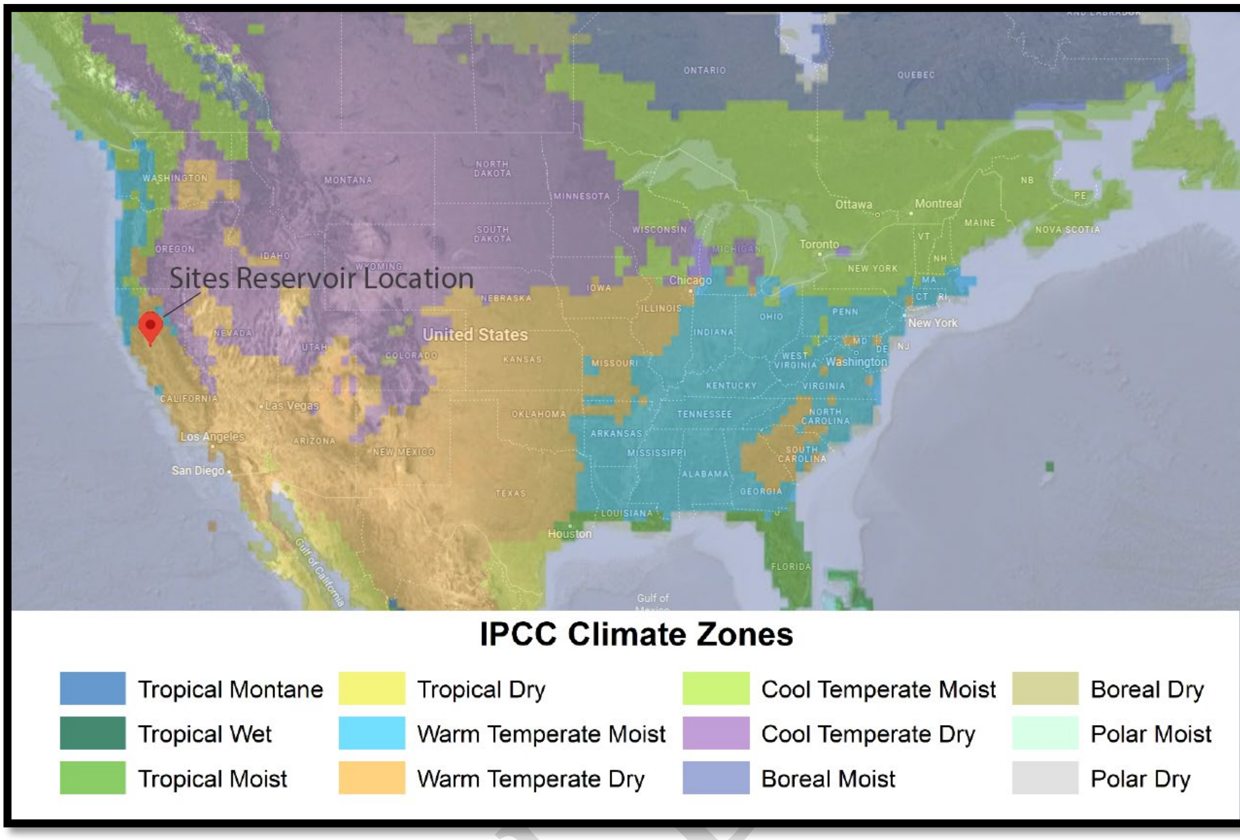
where

α = Emission factor adjustment for trophic state in reservoir *i*, dimensionless. It is 1.0 for Tier 1.

Chla = Mean annual chlorophyll-a concentration in the reservoir, microgram (µg)/liter (L).

At the Tier 2 level, total emissions and downstream emissions can be estimated based on reservoir trophic levels and water withdrawal, respectively. At this time, it is not possible to know the anticipated trophic levels of Sites Reservoir. Therefore, the default Tier 1 value of 1.0 is used for α. Additionally, since Tier 1 is being used for α, the default Tier 1 level of 0.9 is used for R_d for this analysis.

As shown in Figure 21A-1, Sites Reservoir is located in a warm temperate dry zone. The average, lower, and upper 95% confidence interval of the mean CH_4 emission factors for reservoirs greater than 20 years were then used, as per Table 7.9 of the IPCC Guidelines for that climate zone, as shown in Table 21A-1.



Source: Intergovernmental Panel on Climate Change 2019.
Note: IPCC = Intergovernmental Panel on Climate Change.

Figure 21A-1. Sites Reservoir Climate Zone Map

Table 21A-1. CH_4 Emission Factors for Reservoirs Older Than 20 Years—Flooded Land Remaining Flooded Land

Aggregated Climate Zone	CH_4 Emission Factors $EFCH_{4\ age>20,j}$ (kg CH_4/ha-yr)		
	Average	Lower and Upper 95% CI of Mean	
Warm temperate dry	150.9	133.3	168.1

Source: Intergovernmental Panel on Climate Change 2019.
Note: CH_4 = methane; CI = confidence interval; EFCH4 age>20,j = emission factor for CH_4 emitted from the reservoir surface for reservoir >20 years old located in climate zone *j*; ha = hectare; kg = kilogram; yr = year.

For each alternative, the average of the estimated monthly maximum reservoir surface area was calculated and used for the total surface area ($A_{tot\ j}$). These surface areas are shown in Table 21A-2.

Table 21A-2. Maximum Surface Areas for Each Alternative

Alternative	Maximum Monthly Surface Area (ha)												Average of Monthly Maximum
	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	
Alt 1A	5,342	5,342	5,342	5,342	5,342	5,342	5,310	5,276	5,342	5,342	5,342	5,342	5,334
Alt 1B	5,342	5,342	5,342	5,342	5,342	5,341	5,309	5,275	5,340	5,342	5,342	5,342	5,333
Alt 2	4,523	4,523	4,523	4,523	4,523	4,523	4,493	4,461	4,523	4,523	4,523	4,523	4,515
Alt 3	5,342	5,342	5,342	5,342	5,342	5,339	5,306	5,273	5,337	5,342	5,342	5,342	5,332

Note: Alt = alternative; ha = hectare.

Based on the information presented above, annual reservoir and downstream CH_4 emissions for the Sites Reservoir 20 years after its start are presented in Table 21A-3. The table presents average, minimum, and maximum CH_4 emissions.

Table 21A-3. Annual Reservoir, Downstream, and Total CH_4 Emissions for Sites Reservoir After 20 Years

Alternative	Reservoir CH_4 Emissions (metric tons CH_4/yr)	Downstream CH_4 Emissions (metric tons CH_4/yr)	Total CH_4 Emissions (metric tons CH_4/yr)
Average Emissions			
Alt 1A	805	72	877
Alt 1B	805	72	877
Alt 2	681	61	743
Alt 3	805	72	877
Minimum Emissions			
Alt 1A	711	36	747
Alt 1B	711	36	747
Alt 2	602	30	632
Alt 3	711	36	746
Maximum Emissions			
Alt 1A	897	197	1,094
Alt 1B	897	197	1,094
Alt 2	759	167	926
Alt 3	896	197	1,094

Note: Alt = alternative; CH_4 = methane; yr = year.
Values may not sum to the totals due to rounding.

21A.2.2 Lands Converted to Flooded Lands Greenhouse Gas Emissions

The IPCC Guidelines state that the initial flooding of land can cause elevated CO_2 emissions as inundated soil and biomass decay, typically lasting 20 years or less, while oxygen levels are elevated. Conversely, low oxygen levels in the sediment would cause higher CH_4 emissions. Therefore, both CO_2 and CH_4 emissions are analyzed for the initial flooding at Sites Reservoir.

21A.2.2.1 CO_2 Emissions

The IPCC Guidelines have three methodology tiers for analyzing GHG reservoir emissions. Tiers 1 and 2 would involve calculating emissions as follows (Intergovernmental Panel on Climate Change 2019:Equation 7.13):

$$F_{CO2tot} = A_{tot\ j} * EF_{CO2\ age \leq 20j}$$

where

F_{CO2tot} = Total annual emission (removal), metric tons CO_2-C/yr

$A_{tot\ j}$ = Total area of reservoir water surface for the reservoir located in climate zone *j*, ha

$EF_{CO2\ age \leq 20,j}$ = Emission factor in climate zone *j*, metric tons CO_2-C/ha-yr

Tier 3 emissions would use detailed data and models of soil carbon and other remaining carbon pools in the reservoirs that encompass an appropriate range of environmental conditions. This detailed information is not available at this time, so a Tier 3 analysis cannot be implemented.

Tiers 1 and 2 use different emission factors to estimate CO_2 emissions. Tier 1 uses emission factors presented in the IPCC Guidelines. Tier 2 methods for determining annual CO_2 emissions from land converted to flooded land use climate zone and distribution of soil organic carbon (SOC) stock of the land prior to flooding to develop emission factors. These methods are expressed as follows (Intergovernmental Panel on Climate Change 2019:Equation 7.14):

$$EF_{CO2,j} = \phi_k * SOC_{j,k} * M_j$$

where

EF_{CO2j} = Emission factor for the reservoir in climate zone *j*, metric tons CO_2-C/ha-yr

$SOC_{j,k}$ = SOC stock (metric tons C/ha in 0–30 centimeter [cm] depth) values per climate zone *j* and mineral soil type *k* (Intergovernmental Panel on Climate Change 2019:Table 2.3)

ϕ_k = The fraction of reservoir area with soil type *k,* dimensionless

M_j = Scaling factor per climate zone to convert SOC stocks based on empirical relationships between emissions estimated from G-res (integrated 100-year emissions post-flooding reported as a constant yearly flux for the first 20 years post-flooding) and soil C stocks and climate

Sites Reservoir is located in the Antelope Valley, Coast Ranges province. As noted in Chapter 12, *Geology and Soils*, the soils in this province are on gentle to very steep slopes. Most of the soils are clayey and have high expansion potential. The soils are shallow to very deep and have a slight to moderate water erosion hazard. Table 2.3 of the IPCC Guidelines groups each SOC for a given IPCC soil class and defines the high activity clay (HAC) soil class as soils that are lightly to moderately weathered soils dominated by 2:1 silicate clay minerals. Based on this information, it can be assumed that Sites Reservoir would mostly be the HAC soil class. The SOC stocks for this soil class in warm temperate dry climate zone are presented in Table 21A-4.

All values in Table 2.3 of the IPCC Guidelines are presented in the format of the mean for the soil by climate combination ± the 95% confidence limit expressed as a percentage of the mean, which is ±1.96 * standard error/mean *100. In order to calculate a range of CO_2 emissions, the SOC lower and upper 95% confidence limits of the mean are also calculated and shown in Table 21A-4.

Table 21A-4. Default Reference Condition Soil Organic Carbon Stocks (SOC_{REF}) for Mineral Soils (metric tons carbon in 0–30 cm depth)

IPCC Climate Zone	IPCC Soil Class				
	HAC Soils				
	Mean	95% CI As a Percentage of the Mean	Standard Error	Lower and Upper 95% CI of Mean	
Warm temperate dry	24	5%	1.2	21.6	26.4

Source: Intergovernmental Panel on Climate Change 2019.
Note: CI = confidence interval; HAC = high activity clay; IPCC = Intergovernmental Panel on Climate Change.

Values for scaling factor *M* are presented in Table 21A-5.

Table 21A-5. Scaling Factor Value *M* for Annual Onsite CO_2-C Emissions/Removals from Land Converted to Flooded Land

IPCC Climate Zones	*M*		
	Average	Lower and Upper 95% CI	
Warm temperate dry	0.0568	0.0541	0.0595

Source: Intergovernmental Panel on Climate Change 2019.
Note: CI = confidence interval; IPCC = Intergovernmental Panel on Climate Change; *M* = scaling factor.

Tier 2 CO_2 emission factors for lands converted to flooded lands are then calculated and presented, along with the Tier 1 emission factors, in Table 21A-6.

Table 21A-6. CO_2-C Emission Factors for Reservoirs ≤20 Years Old—Land Converted to Flooded Land

Tier	Climate Zone	CO_2-C Emission Factors $EF_{CO2\ age\leq20,j}$ (metric tons CO_2-C ha-1 yr-1)		
		Average	Lower and Upper 95% CI of Mean	
1	Warm temperate dry	1.7	1.66	1.75
2	Warm temperate dry	1.4	1.17	1.57

Source: Intergovernmental Panel on Climate Change 2019.
Note: C = carbon; CI = confidence interval; CO_2 = carbon dioxide; $EF_{CO2\ age\leq20,j}$ = emission factor in climate zone *j*; ha = hectare; yr = year.

The Tier 1 emission factors are then used to calculate the CO_2 emissions for lands converted to flooded lands at Sites Reservoir up to 20 years after it starts in order to be conservative (Table 21A-7). The maximum reservoir surface areas presented in Table 21A-2 were used in the calculation.

Table 21A-7. Annual Reservoir CO_2 Emissions for Sites Reservoir Up to 20 Years

Alternative	Total CO_2 Emissions (metric tons CO_2/yr)
Average Emissions	
Alt 1A	9,067
Alt 1B	9,067
Alt 2	7,676
Alt 3	9,065
Minimum Emissions	
Alt 1A	8,854
Alt 1B	8,853
Alt 2	7,495
Alt 3	8,852
Maximum Emissions	
Alt 1A	9,334
Alt 1B	9,333
Alt 2	7,901
Alt 3	9,332

Note: Alt = alternative; CO_2 = carbon dioxide; yr = year.

21A.2.2.2 CH_4 Emissions

Similar to CH_4 emissions estimates for lands remaining flooded lands, CH_4 emissions for lands converted to flooded land are estimated as follows (Intergovernmental Panel on Climate Change 2019:Equation 7.15).

$$F_{CH4tot} = F_{CH4res} + F_{CH4downstream}$$

$$F_{CH4res} = \alpha\ (EF_{CH4\ age \leq 20,j} * A_{tot\ j})$$

$$F_{CH4downstream} = \alpha\ (EF_{CH4\ age \leq 20,j} * A_{tot\ j}) * R_d$$

where

F_{CH4tot} = Total annual emission of CH_4, kg CH_4/yr

F_{CH4res} = Annual reservoir surface emissions of CH_4, kg CH_4/yr

$F_{CH4downstream}$ = Annual emissions of CH_4 emitted downstream of dam, kg CH_4/yr

$A_{tot\ j}$ = Total area of reservoir water surface located in climate zone *j*, ha

$EF_{CH4\ age \leq 20,j}$ = Emission factor for CH_4 emitted from the reservoir surface for reservoir ≤20 years old located in climate zone *j*, kg CH_4/ha-yr

R_d = A constant equal to the ratio of total downstream emission of CH_4 to the total flux of CH_4 from the reservoir surface [dimensionless]. It is 0.09 by default for Tier 1 and zero for all other reservoirs.

α = Emission factor adjustment for trophic state in reservoir *i* within a given climate zone [dimensionless]. It is 1.0 by default for Tier 1.

As stated above for flooded lands remaining flooded lands, the default value of 1.0 is used for α. Additionally, the median level of 0.9 is used for R_d for this analysis.

The average and lower and upper 95% confidence interval of the mean CH_4 emission factors for reservoirs up to 20 years were then used, which are presented in Table 21A-8.

Table 21A-8. CH_4 Emission Factors for Reservoirs ≤20 Years—Land Converted to Flooded Land

Aggregated Climate Zone	CH_4 Emission Factors $EF_{CH4\ age>20,j}$ (kg CH_4/ha-yr)		
	Average	Lower and Upper 95% CI of Mean	
Warm temperate dry	195.6	176.9	214.7

Source: Intergovernmental Panel on Climate Change 2019:Table 7.15.
Note: CH_4 = methane; CI = confidence interval; $EF_{CH4\ age>20,j}$ = emission factor for CH_4 emitted from the reservoir surface for reservoir ≤20 years old located in climate zone *j*; ha = hectare; kg = kilogram; yr = year.

Annual reservoir and downstream average and minimum and maximum CH_4 emissions for Sites Reservoir up to 20 years after its start are presented in Table 21A-9.

Table 21A-9. Annual Reservoir, Downstream, and Total CH_4 Emissions for Sites Reservoir Up to 20 Years

Alternative	Reservoir CH_4 Emissions (metric tons CH_4/yr)	Downstream CH_4 Emissions (metric tons CH_4/yr)	Total CH_4 Emissions (metric tons CH_4/yr)
Average Emissions			
Alt 1A	1,043	94	**1,137**
Alt 1B	1,043	94	**1,137**
Alt 2	883	79	**963**
Alt 3	1,043	94	**1,137**
Minimum Emissions			
Alt 1A	944	47	**991**
Alt 1B	944	47	**991**
Alt 2	799	40	**839**
Alt 3	943	47	**990**
Maximum Emissions			
Alt 1A	1,145	252	**1,397**

Alternative	Reservoir CH_4 Emissions (metric tons CH_4/yr)	Downstream CH_4 Emissions (metric tons CH_4/yr)	Total CH_4 Emissions (metric tons CH_4/yr)
Alt 1B	1,145	252	**1,397**
Alt 2	969	213	**1,183**
Alt 3	1,145	252	**1,397**

Note: Alt = alternative; CH_4 = methane; yr = year.
Values may not sum to the totals due to rounding.

21A.2.3 Greenhouse Gas Reservoir Emissions Results Summary

Total GHG emissions for Sites Reservoir are presented in Table 21A-10. An average and a minimum to maximum range are presented for each alternative during the reservoir's first 20 years and then after that 20-year period. CO_2 and CH_4 emissions are combined to show the total CO_2 equivalent (CO_2e) emissions.

Table 21A-10. Annual Reservoir Greenhouse Gas Emissions for Sites Reservoir

			Metric tons per Year					
			Average GHG Emissions			GHG Emission Range		
Land Use	**Calculation Scenario**	**Alternative**	**CO_2**	**CH_4**	**Total CO_2e**	**CO_2**	**CH_4**	**Total CO_2e [a]**
Reservoir ≤20 yrs	Lands Converted to Flooded Land	1A	9,067	1,137	37,496	8,854–9,334	991–1,397	33,622–44,261
Reservoir >20 yrs	Flooded Land Remaining Flooded Land		–	877	21,932	–	747–1,094	18,663–27,346
Reservoir ≤20 yrs	Lands Converted to Flooded Land	1B	9,067	1,137	37,494	8,853–9,333	991–1,397	33,619–44,258
Reservoir >20 yrs	Flooded Land Remaining Flooded Land		–	877	21,931	–	746–1,094	18,662–27,344
Reservoir ≤20 yrs	Lands Converted to Flooded Land	2	7,676	963	31,742	7,495–7,901	839–1,183	28,462–37,468
Reservoir >20 yrs	Flooded Land Remaining Flooded Land		–	743	18,566	–	632–926	15,799–23,149
Reservoir ≤20 yrs	Lands Converted to Flooded Land	3	9,065	1,137	37,488	8,852–9,332	990–1,397	33,614–44,251
Reservoir >20 yrs	Flooded Land Remaining Flooded Land		–	877	21,927	–	746–1,094	18,659–27,340

Note:

CH_4 = methane; CO_2 = carbon dioxide; CO_2e = carbon dioxide equivalent; GHG = greenhouse gas; yrs = years.

[a] CH_4 emissions are multiplied by 25 to get CO_2e.

21A.3 Calculation Uncertainties

The factors used to calculate the emissions presented above are based on data from a range of reservoirs collected throughout the world. Given the range of reference data used in this analysis, the estimated future emissions of the proposed reservoir include some amount of uncertainty. While Tier 2 or 3 emissions calculations could be used to reduce the degree of uncertainty, these calculation methods require site-specific reservoir data, which is not available for the Project given that it has not been implemented and the reservoir has not yet been created. Accordingly, the Tier 1 calculation method was used, as described above, and as such, actual future reservoir emissions may deviate from those estimated in this analysis.

The U.S. Environmental Protection Agency developed the *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990–2020* (U.S. Environmental Protection Agency 2022) using the IPCC (2019) guidelines. Emissions from land converted to flooded land and flooded land remaining flooded land in the guidelines are covered under the category of Land Use, Land-Use Change and Forestry (LULUCF). Annex 7 of the guidelines identifies uncertainties on its 2020 LULUCF emissions inventory of -17% for the lower bound and +18% for the upper bound for the 95% confidence interval. Emissions from the proposed reservoir could therefore vary from the estimated intervals presented in Table 21A-10 by about +/- 18%. It should be noted, however, that the LULUCF inventory includes emissions from other sources, such as forest fires and coastal wetlands, which may influence the degree of uncertainty estimated by the IPCC.

In addition, emissions are expected to be higher during the first 20 years after flooding, with stabilization of land-use emissions over time. The IPCC 2019 revision states that "statistical analyses on reservoirs worldwide indicate that there is a rapid surge of emissions immediately following flooding, after which emissions stabilize." The rate of the post-flooding decrease in emissions may depend on the region in which a reservoir is located and can differ between CO_2 and CH_4 but seems to occur "mainly during the initial decade following flooding". Additionally, other research has shown that the CO_2 emissions surge immediately after impoundment and then quickly recede in the following years with negligible CO_2 emissions after 10 years, but can conservatively take up to 100 years (e.g., Yang et al. 2014; Prairie et al. 2018). Emission levels toward the maximum of the range presented in Table 21A-10 are therefore expected during the first decade after flooding, with a shift toward the lower range over time. However, it is uncertain how long after flooding emission will decline as it may take anywhere from 10 to 100 years for an equilibrium to be established.

21A.4 References

21A.4.1 Printed References

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