The Climate Registry

Water-Energy-GHG Guidance

Gap Analysis

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SCE chartered this effort in response to SCE business customers' requests for a resource to help them accurately determine the GHGs associated with energy embedded in water and to provide education about the water-energy nexus to support SCE's Integrated Demand Side Management Efforts.

This Gap Analysis was developed with substantial input from stakeholders in the water sector. The Climate Registry thanks the members of the Technical Review Team that provided valuable feedback on a draft version of the WEG Guidance Gap Analysis.

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Introduction

The Climate Registry (TCR) is a non-profit that assists organizations in measuring, reporting and verifying (MRV) the carbon in their operations in order to manage and reduce it. TCR supports these organizations by operating a voluntary greenhouse gas (GHG) reporting program built on GHG accounting and reporting best practices. General guidance for TCR's voluntary program is provided through the General Reporting Protocol (GRP) and General Verification Protocol (GVP). TCR also develops sector-specific guidance. Currently, customized guidance is available for local government operations, the electric power industry, public transit, oil and gas exploration and production, and urban water management. These protocols are developed and maintained through consensus-based processes that include input from TCR directors, members, and relevant industry and sector-specific experts.

TCR's existing guidance for urban water managers, known as the Water-Energy-GHG Guidance Version 1 (WEG 1.0)[1], was developed with support from Southern California Edison (SCE) and published in December, 2015. WEG 1.0 provides guidance to SCE business customers in measuring the emissions intensity of the collection, extraction, transport, treatment and delivery of potable and raw (or untreated) water in Southern California. In order to better understand emissions associated with water management in the region, TCR is currently updating WEG 1.0 to include guidance for measuring the emissions intensity of activities associated with wastewater and recycled water management.

1. See Water-Energy GHG Guidance, GHG Intensity Metrics for Water Suppliers in Southern California, Version 1.0: http://www.theclimateregistry.org/wp-content/uploads/2015/12/Water-Energy-GHG-Guidance-December-2015.pdf

Background

Following the publication of WEG 1.0, TCR and SCE piloted the guidance with 15 water suppliers in Southern California in order to ensure the methodologies included within it credibly and consistently communicated the relative emissions intensity of the various water supplies and water management processes. While some minor suggestions for refinement were identified, a core outcome of the pilot was an understanding that as advanced downstream water treatment processes continue to become more sophisticated, and reclaimed water continues to be considered a potential long term supply for meeting Southern California's increasing water demand, it will be important to understand the emissions trends associated with these water management activities. TCR and SCE will be developing a WEG Guidance Version 2 (WEG 2.0) to address these issues through an open stakeholder process that includes a series of four stakeholder workshops throughout 2018.

Purpose and Organization

This gap analysis identifies information that will need to be addressed in the development of WEG 2.0. Its content was evaluated by a Technical Review Team of 25 individuals with a diverse range of expertise and experience who represent 14 distinct organizations from the water sector in order to provide appropriate background information on the issues that will be discussed throughout the stakeholder process. Additional feedback on this analysis can be provided by emailing policy@theclimateregistry.org or through participation in the ongoing stakeholder process.

There are two broad goals to be addressed in the development of WEG 2.0, and the gap analysis is therefore presented in two parts. The first goal is to update and clarify the content of WEG 1.0 to ensure that it remains useful and relevant to urban water managers. As such, the gap analysis begins with an

outline of content in WEG 1.0 that will require update or clarification and key considerations in updating that content.

The second goal is to expand the scope of the guidance to include additional metrics that measure the emissions intensity of wastewater management processes or recycled water products. The second part of the analysis overviews processes related to wastewater and recycled water management that produce GHG emissions, and then presents key issues that should be considered in the development of emissions intensity metrics for those operations and products.

A high-level literature review is also provided, which outlines relevant resources that will be consulted in the development of WEG 2.0.

Throughout the gap analysis, questions are posed to stakeholders to invite feedback on the recommended or proposed updates to WEG 1.0. These questions are presented in blue text and emphasized with italics.

A high-level literature review is also provided, which outlines relevant resources that will be consulted in the development of WEG 2.0.

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Part I: WEG 1.0 Updates and Clarifications

Updates and clarifications to TCR's guidance documents are necessary as emissions measurements technologies or estimation methodologies are refined and user feedback is collected. Issue areas identified in WEG 1.0 during the WEG Pilot are outlined in Table 1 below. The issue areas are presented in the order of the chapters and sections of WEG 1.0, alongside key considerations in updating the content. Where issue areas presented in Table 1 are relevant to wastewater and recycled water operations, reviewers are directed to Part 2 of this gap analysis for further discussion.

TABLE 1: Addressing Gaps in Existing WEG 1.0 Content

Issue Area	Gap in Current Guidance (WEG 1.0)	Desired Guidance (WEG 2.0)	Key Considerations
Part I: Introduction			
Applicability	Not addressed: • Guidance and WEG metrics for wastewater, recycled water, or groundwater basin managers.	Address guidance for the following water agencies in WEG 2.0: • Wholesalers; • Retailers; • Irrigation districts; • Publicly-owned treatments works (POTWs); • Groundwater replenishment districts, watermasters, and sustainable groundwater management authorities.	A complete list of the types of water agencies currently addressed in WEG 1.0 can be found on pages 3-5 of that document[2].
Part II: Determining What to Report			
Reporting period (i.e., generating valuable data for tracking emissions intensity over time)	Not addressed: • Temporal variability within a calendar year; • Resource changes year-to-year.	WEG 2.0 will continue to require annual, calendar year data for reporting WEG metrics, however some additional guidance will be provided to water agencies who are interested in tracking WEG metrics on a quarterly timescale. *Is your organization interested in tracking WEG metrics on quarterly (or smaller) timescales?*	Tracking WEG metrics on a quarterly basis could help organizations to better understand the impacts of seasonal weather variation on the emissions intensity of their operations.
Operational boundary (emissions)	Not addressed: • Direct or indirect emissions associated with wastewater or recycled water management (including upstream or downstream Scope 3 emissions);	Ensure that emissions associated with wastewater and recycled water operations are considered within operational boundaries. Include guidance on accounting for indirect emissions associated with water management according to GRP version 2.1 requirements, and clarify how this	See Part 2 of this gap analysis for further discussion of wastewater and recycled water emissions. Version 2.1 of TCR's GRP[3], was published in March, 2016 and includes updated guidance for reporting Scope 2 emissions in

2. *Ibid.*
3. See General Reporting Protocol for the Voluntary Reporting Program, Version 2.1: https://www.theclimateregistry.org/wp-content/uploads/2014/11/General-Reporting-Protocol-Version-2.1.pdf

Issue Area	Gap in Current Guidance (WEG 1.0)	Desired Guidance (WEG 2.0)	Key Considerations
	• Consequential or non-consequential hydropower generation; • Measuring WEG intensity metrics with two indirect (Scope 2) emissions totals.	impacts WEG metrics. For example, guidance will be provided for measuring WEG metrics using either the market- or location-based methods (Scope 2). The guidance will clarify how WEG metrics differ from energy intensity metrics.	accordance with international best practice[4].
Water use cycle	Not addressed: • Water end use (i.e., residential, industrial, or agricultural water consumption or use); • Recycled water treatment, storage, or distribution; • Wastewater collection, treatment, or discharge.	Ensure that wastewater and recycled water operations are addressed in the water use cycle from a water manager's perspective. *How should the guidance define the "water use cycle" so that it is inclusive of wastewater operations like biogas and biosolids management? And recycled water operations like advanced treatment and delivery?* *What specific processes associated with wastewater and recycled water management would be valuable to track using WEG metrics?*	For a full list of existing processes or "steps" in the water use cycle see page 7 of WEG 1.0. For further discussion of wastewater or recycled water processes see Part 2 of this analysis. The guidance should be consistent with DWR's guidance on measuring the energy intensity of recycled water, which suggests that only the additional energy required to move reclaimed wastewater through the remaining aspects of the water use cycle (point of treated wastewater discharge to beneficial reuse, rather than from point of wastewater collection to reuse)[5] be considered when measuring the energy intensity of recycled water products. DWR groups the wastewater and recycled water processes used for reporting energy intensity as collection, treatment, and discharge/distribution. However, this list does not include processes associated with biogas or biosolids management.

4. See GHG Protocol Scope 2 Guidance, an amendment to the GHG Protocol Corporate Standard: https://ghgprotocol.org/sites/default/files/standards/Scope%202%20Guidance_Final_0.pdf

5. See DWR 2015 UWMP Guidebook Appendices, Appendix O Voluntary Energy Intensity Reporting, *Recycled Water Energy Intensity*: http://wdl.water.ca.gov/urbanwatermanagement/docs/2016/2015%20UWMP%20Guidebook%20Appendic es%20FINAL.pdf

Issue Area	Gap in Current Guidance (WEG 1.0)	Desired Guidance (WEG 2.0)	Key Considerations
Part III, Overview of WEG Intensity Metrics			
Delivered Water	Clarification is required around the definition of delivered water for the existing composite WEG metrics A and B. Specifically, additional guidance is required in accounting for delivered water volumes that are not delivered to the retail distribution system (e.g., water placed into long-term storage, used for groundwater recharge, or wastewater that is treated for safe discharge to ecosystems). Not addressed: • Discharged wastewater volumes in units other than AF; • Water losses; • Water used for groundwater recharge; • Recycled water products.	Clarify the definition of delivered water for specific types of water suppliers. For example, ensure that the definition of delivered water is inclusive of wastewater managers who do not deliver any water directly to the retail distribution system, but instead move treated wastewater to discharge sites or recycled water to groundwater recharge sites. Wholesalers move water to other water agencies or storage sites, and do not deliver water directly to retail end users either. Provide guidance on accounting for water losses according to industry best practice and relevant reporting requirements. *What unit of measure should the guidance rely on for discharged wastewater?*	The definition of delivered water directly affects composite WEG metric since it is the resource that emissions are being normalized against (i.e., the denominator of the metrics). The WEG 1.0 definition excludes water volumes that are not directly delivered to the retail distribution system in the calendar year being reported (relevant text on page 9). At the time of WEG 1.0 publication, water losses were not directly addressed due to a lack of available data and accepted industry best practice. Now, California legislation requires that some water agencies complete annual water loss reporting, audits, and validation[6], which will be considered in WEG metric development. If the WEG guidance allows annual WEG metrics for wastewater processes to be reported in metric tons per million gallons (mt/MG), wastewater-related WEG metrics will be distinguished from all other WEG metrics, which are reported in metric tons per AF (mt/AF).

6. See California SWRCB Water Loss Control Program (SB 555) website: https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/water_loss_control.html

Issue Area	Gap in Current Guidance (WEG 1.0)	Desired Guidance (WEG 2.0)	Key Considerations
Part IV: Methodology – Step 2			
Measuring process-specific emissions	Not addressed: • Guidance for allocating emissions between distinct process or "steps" in the water use cycle.	*How should the guidance address allocating emissions between water management processes that exist on the same energy meter?* For example, DWR's guidance on measuring energy intensity suggests that water agencies either use their best judgement to partition the energy consumption between the multiple processes that exist on the same meter, or to classify the energy requirements as one specific process or the other, without double counting[7].	Discrete water management processes, or "steps" in the water use cycle, are used to identify emissions that pertain to water management, and to organize that emissions data into process-specific WEG metrics. However, multiple water management processes (e.g., extraction and treatment) are often tracked on the same energy meters. As a result, suppliers face challenges in developing process-specific WEG metrics for each distinct step in the water use cycle due to a lack of granular data availability.

7. See DWR 2015 UWMP Guidebook Appendices, Appendix O Voluntary Energy Intensity Reporting, *Water Management Processes*: http://wdl.water.ca.gov/urbanwatermanagement/docs/2016/2015%20UWMP%20Guidebook%20Appendic es %20FINAL.pdf

Part 2: Incorporating Guidance for Wastewater and Recycled Water

Wastewater and recycled water operations include unique processes that are not currently addressed in the WEG 1.0 guidance. The direct emissions associated with wastewater management include carbon dioxide (CO_2) from internal combustion, methane (CH_4) from anaerobic lagoons and digestion, and nitrous oxide (N_2O) emissions from nitrification and denitrification. Indirect emissions associated with purchased and consumed power also result from the collection, treatment, and discharge of wastewater or distribution of recycled water. Wastewater management is often more energy intensive than drinking water treatment due primarily to the high energy needs for supporting the biodegradation of waste. While the energy intensity of wastewater management may be high, wastewater treatment plants are often able to avoid purchasing power from the electric grid by capturing biogas that results from anaerobic digestion of sewage sludge and using it to generate their own power on site.

The remainder of this gap analysis explores the processes within wastewater management that WEG intensity metrics could meaningfully group and track, and also aims to define recycled products.

Overview of Wastewater Management Processes

The major components of the wastewater management system are outlined below in order to facilitate a conversation around the discrete processes or “steps” that would be useful for wastewater and recycled water managers tracking WEG intensity metrics.

1. **Collection**

   The wastewater management process begins downstream of customers or end users with the collection of wastewater flows. Wastewater collection systems predominantly use gravity to move water, which has no energy cost and thus no GHG implications. Some agencies must rely on pump or lift stations, which can be energy intensive. As efficiency and conservation efforts continue to reduce flows in wastewater collection systems, solids settling may become an increasing challenge, forming anoxic zones, and the potential for GHG production within sewer systems.

   What existing resources, if any, are available to quantify emissions occurring within wastewater collections systems?

2. **Treatment**

   Wastewater treatment can be accomplished through many different combinations of processes, each having different energy intensities. The combination employed is generally controlled by site-specific conditions like ambient temperature, pollutants, and treatment objectives. Typically, wastewater treatment is conceptually segmented in physical, chemical, and biological treatment components.

   a. Physical treatment is the passive separation of waste through settling, and generally does not require significant energy demand.

   b. Chemical treatment does not produce GHGs directly, but energy demands associated with these processes will be considered.

   c. Biological treatment relies on microbes to treat waste, and is generally considered the most energy intensive component of the wastewater treatment process since a steady flow of oxygen through the waters must be maintained.

The treatment processes described above (or combined treatment "streams" or "lines") will be grouped into a single process-specific WEG metric for each of DWR's Title 22[8] defined treatment levels as appropriate. For example, the process-specific WEG metrics could be defined as screenings, pretreatment, primary, secondary, tertiary, and disinfection.

3. Biogas Utilization

Biogas is an important product generated when processing sewage sludge from wastewater treatment plants. It can be a useful energy source when burned in a generator, and can sometimes be converted to biofuel for transportation fleets. On-site biogas use is common in larger plants and can generate enough energy to power some systems entirely. When using biogas in a stationary combustion engine, there is little need for post-production treatment with the exception of low energy intensity sulfur removal. In cases where biogas will be converted to biofuels or sold commercially, treatment and pressurization can quickly become energy intensive requirements. In all biogas operations, excess biogas is flared[9].[10]

What direct and indirect emissions from biogas treatment, if any, should be considered in the guidance?

What resources are available for quantifying the emissions benefits of biosolids for carbon sequestration or offsetting the use of fossil fuel intense inorganic fertilizer?

4. Solid Waste Handling

Biosolids collected following anaerobic digestion are dewatered either mechanically or thermally. Dewatered biosolids can be applied to land as sources of nitrogen and phosphorus which have multiple GHG benefits like increasing carbon sequestration in soils and offsetting the use of inorganic fertilizers.

Regardless of beneficial use, biosolids need to be physically removed from the wastewater treatment plant site, and it is most often done by third-party hauling trucks. In order to reduce the load of solids transported, some plants choose to incinerate their waste.

What indirect Scope 3 emissions associated with biosolid applications, if any, should be considered in the guidance?

What resources are available for quantifying the emissions benefits of biosolids for carbon sequestration or offsetting the use of fossil fuel intense inorganic fertilizer?

5. Recycled Water Distribution

Much the same as potable water pumping, distribution of recycled water can require significant energy. This is especially true because wastewater treatment facilities tend to be downslope from their customers (to allow for gravity flow of wastewater), and thus the product water must be pumped back uphill.

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8. See U.S. Environmental Protection Agency Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field: https://www.epa.gov/sites/production/files/2015-07/documents/opportunities_for_combined_heat_and_power_at_wastewater_treatment_facilities_market_analysis_and_lessons_from_the_field.pdf

9. See Brown and Caldwell, Evaluation of Combined Heat and Power Technologies for Wastewater Treatment Facilities: http://water.epa.gov/scitech/wastetech/publications.cfm

10. See Brown and Caldwell, Evaluation of Combined Heat and Power Technologies for Wastewater Treatment Facilities: http://water.epa.gov/scitech/wastetech/publications.cfm

Defining Wastewater Management Processes for the Water Use Cycle

As mentioned in Part 1 of this gap analysis, DWR's guidance on energy intensity reporting for wastewater and recycled water operations outlines the processes related to these types of water as collection/ conveyance, treatment, and discharge/distribution[11]. However, this list does not include processes associated with managing the other products of wastewater: biogas or biosolids.

Considering the discussion above, how should the guidance define wastewater and recycled water processes in order to organize and track annual processes-specific WEG metrics?

How should these processes be incorporated into the overall water use cycle?

Should the emissions that result from biogas and biosolids management be included within composite WEG metrics that communicate the overall emissions intensity of managing discharged wastewater or recycled water products? Or should the emissions associated with biogas or biosolid management only be considered separately?

Defining Recycled Water Products

In California it is commonplace for wastewater treatment facilities to treat wastewater up to a secondary or tertiary treatment level (please refer to the table below for more details on these treatment types)[12]. Many plants sell wastewater treated to these levels as recycled water products. The California Water Code defines recycled water products by the different quality standards which affect a recycled water's functionality[13], energy intensity[14], and GHG emissions[15]. Table 2 describes broad categories for recycled water products and acceptable uses as outlined by the California Department of Water Resources. Each level of treatment is achieved through additional processes which increase energy demand.

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11. See U.S. Environmental Protection Agency California Clean Watershed Needs Survey: https://www.epa.gov/sites/production/files/2015-10/documents/cwns_fs-ca.pdf

12. See State of California (2000). Water recycling criteria. California code of regulations, Title 22, Article 3 California Department of Health Services, Sacramento, CA: https://www.cityofventura.ca.gov/DocumentCenter/View/6327/Regulations-Related-to-Recylecd-Water

13. See WaterReuse Research Foundation. Framework for Direct Potable Reuse: https://watereuse.org/wp-content/uploads/2015/09/14-20.pdf

14. See WaterReuse Research Foundation. Framework for Direct Potable Reuse: https://watereuse.org/wp-content/uploads/2015/09/14-20.pdf

15. The Opportunities and Economics of Direct Potable Reuse. WaterReuse Research Foundation.

TABLE 2: Recycled Water Products by Level of Treatment

Treatment Level	Beneficial Use Permitted by Title 22[16]	Energy Intensity (kWh/AF)[17]
Advanced	• Groundwater recharge by subsurface injection • Sea water intrusion barriers by subsurface injection • To be considered as part of the surface reservoir augmentation and direct potable reuse	1120-1870
Disinfected Tertiary	• Urban residential use- landscaping, golf courses, school yards • Commercial use- laundries, artificial snow-making • Industrial use- process water with worker contact, cooling, and air conditioning • Groundwater recharge by surface application	520-670
Disinfected Secondary 2.2		330-520
Disinfected Secondary 23	• Agricultural use- nurseries and sod farms with unrestricted access • Urban use- freeway landscaping, golf courses with restricted access • Commercial use- boiler feedwater, concrete mixing, soil compaction	330-520
Undisinfected Secondary	• Agricultural use- fodder, fiber, and seed crops; nursery and sod farm irrigation • Other sanitary sewer flushing	*If your organization provides this product, please share your experience.*

16. See California Department of Water Resources, California Recycled Water Use in 2015. International Water Association Conference Presentation: https://water.ca.gov/LegacyFiles/recycling/docs/2015RecycledWaterSurveySummary_EnglishUnits.pdf

17. See WaterReuse Research Foundation. *Framework for Direct Potable Reuse*: https://watereuse.org/wp-content/uploads/2015/09/14-20.pdf

Exploring Emissions Intensity Metrics for Wastewater and Recycled Water

WEG 1.0 describes three composite metrics that include a system-wide average (Metric A), a system-wide average with upstream emissions incorporated (Metric B), and a product specific metric (Metric C).

When considering wastewater however, there are additional metrics which may be useful. Table 3 provides an overview of WEG 1.0 metrics, a discussion of how those metrics might be adjusted to include wastewater and recycled water operations, and proposals for additional metrics related to wastewater and recycled water management.

TABLE 3: Metric Considerations for WEG 2.0

Metric	Metric Scope	Units	Description and Key Considerations
Metric A	System-wide Average	GHG/AF	Provides a basic, annual average of all entity-wide emissions pertaining to water. Wastewater and recycled water managers can rely on this metric to evaluate basic emissions trends in their own operations once the WEG 1.0 definition of “delivered water” is revised.
Metric B	System-wide Average with Upstream Scope 3	GHG/AF	Provides a basic, annual average of system-wide emissions pertaining to water across a region by incorporating Scope 3 emissions. Helps users understand emissions trends beyond their own organizational boundaries by considering emissions that are embedded in the water that they receive from upstream suppliers. Including embedded Scope 3 emissions in WEG metrics could help water managers and consumers to better understand the GHG implications of relying on local, recycled water supplies versus importing or extracting virgin water supplies. Water managers could also use a version of this metric to develop a “recharge-specific" WEG metric, which considers the weighted emissions intensities of all water supplies used for groundwater recharge within a basin, once the definition of “delivered water” is revised.

Metric C	Product-Specific with Upstream Scope 3	GHG/AF	Provides a basic, annual average of emissions specific to each water product that an agency delivers or sells. This can be useful for agencies that produce and sell multiple products, and for recycled water managers who sell water treated to various DWR Title 22 treatment levels for a variety of end uses.
Process-specific Metric A, B, C	Specific to each step in the water use cycle	GHG/AF	Provides emissions specific to each process or "step" in the water use cycle, including extraction/diversion, conveyance, placing water into storage, treatment, and distribution. Wastewater and recycled water managers can rely on these metrics to evaluate emissions trends in their own operations once the WEG 1.0 definition of "water use cycle" is revised.
Metric D	*System-wide Average with Downstream Scope 3*	*GHG/AF*	*Aims to provide a basic, annual average of all entity-wide emissions pertaining to water, while considering the GHGs that occur downstream of a water agency.* *What downstream Scope 3 emissions from water, biosolid, or biogas management would it be appropriate to include within this metric, and still avoid double counting of emissions benefits? What resources are available for quantifying these emissions?*
Metric E	*System-wide – Biogas or Biosolids Management*	*GHG/scf biogas* *GHG/kWh produced* *GHG/GGE* *GHG/dry ton of biosolids*	*Aims to provide a basic, annual average of all entity-wide emissions pertaining to wastewater management normalized to resources other than water (e.g. dewatered solids, biogas, energy, or "renewable biofuels").* *What products or resources other than delivered water would it be helpful for wastewater or recycled water utilities to normalize their water operations to? What units should they be reported in?*

Literature Review

While the Intergovernmental Panel on Climate Change (IPCC), The United State Environmental Protection Agency (U.S. EPA), the California Air Resources Board (CARB) and others have worked to estimate GHG emissions from wastewater on a gross basis, the methodologies focus on “top-down” approaches to estimating wastewater management emissions for an entire state or country. There are not widely-accepted, standardized, and reproducible guidelines to estimate emissions from wastewater treatment at a facility level. A recent review paper concluded that the current complexity of models required to generate accurate emissions results prohibits many wastewater treatment facilities from producing their own estimates independently.

Wastewater quantification methods often require detailed biological or chemical profiles of the wastewater facility operations, and this data is not readily available to many wastewater managers.

Tables 4 and 5 below outline the high-level resources that will be considered in the development of additional metrics in WEG 2.0. (Arranged by lead author’s name/title.)

What guidance or resources for benchmarking, tracking, or reducing emissions from wastewater management over time should be added to the list below?

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18. See: Mannina. G., Ekama, G., Caniani, D., Cosenza, A., Esposito, G., Gori, R., Garrido-Baserba, M., Rosso, D., Olsson, G. (2016) Greenhouse Gases from Wastewater Treatment- A Review of Modelling Tools, Science of the Total Environment

TABLE 4: Models and Methodologies for Consideration in WEG 2.0 Development

Resource	Relevance to WEG 2.0
Urban Water Management Plans Guidebook for Urban Water Suppliers, Appendix O **California Department of Water Resources, 2015**	Includes guidance for measuring voluntary energy intensity metrics for various water products, including recycled and wastewater on an annual basis.
Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2004 **California Energy Commission, 2006**	Top-down approach for measuring GHGs at large scale. Utilizes the Emissions Inventory Improvement Program (U.S. EPA, 1999) methodology, which is noted to over-estimate GHG emissions.
California 2000-2014 Greenhouse Gas Emissions Inventory **California Environmental Protection Agency: Air Resources Board, 2016**	CH_4 and N_2O estimations which build on the IPCC 2006 standards using the U.S. EPA's U.S. Greenhouse Gas Emissions and Sinks:1990-2013 research (2015) and California-relevant improvements where possible.
Biosolids Emissions Assessment Model (BEAM) **Canadian Council of Ministries of the Environment, 2009**	GHG estimation tool for biosolids processing, which includes the downstream effects of biosolid land application like carbon sequestration and avoided fertilizer use.
Guidelines for National Greenhouse Gas Inventories Volume 5 **Intergovernmental Panel on Climate Change, 2006**	Global and national estimates for GHG emissions from waste and wastewater management. These Guidelines present the international standard for measuring GHG emissions from wastewater.
Local Government Operational Protocols (LGOP) for Greenhouse Gas Assessment **The Climate Registry, 2010**	Provides guidance on GHG emissions measurements, relying largely on the existing "top-down" methodologies used by ARB and U.S. EPA to estimate emissions for an entire state or country.
Greenhouse Gas Emissions Estimation Methodologies for Biogenic Emissions from Selected Source Categories **U.S. Environmental Protection Agency, 2010**	GHG estimation tool for solid waste management, wastewater treatment, and ethanol formation. Also includes estimations for GHG emission from biogas combustion, landfills, and solids waste composting.
A High-Resolution Approach to Mapping Energy Flows through Water Infrastructure Systems. **University of California Davis, Spang and Loge, 2015**	Includes detailed methods for measuring the energy intensity of water management operations specific to each supplier.

TABLE 5: Literature for Consideration in WEG 2.0 Development

Resource	Relevance to WEG 2.0
The Role of Recycled Water in Energy Efficiency and Greenhouse Gas Reduction **California Sustainability Alliance, 2008**	Examines broadly the role of recycled water in shifting GHG emissions and provides an example of quantifying the relative benefit of recycled water to a supply alternative (Table 4-15).
Discussion Paper for Wastewater Treatment Plant Sector Greenhouse Gas Emissions Reporting Protocol **California Wastewater Climate Change Group & Bay Area Clean Water Agencies, 2007**	Describes wastewater treatment GHG emissions specific to California. Summarizes and assesses the value of the IPCC, U.S. EPA, and CEC GHG emissions protocols. Provides recommendation on accounting boundaries, as well as characterizes facility and state-wide baseline emissions.
Greenhouse Gas Emissions from Integrated Urban Drainage Systems (IUDS): Where do we stand? **Mannina et al., 2018**	Describes recently developed qualitative modelling tools and a framework for examining GHG emissions from IUDSs, including sewer systems. This work also highlights the gaps in knowledge and challenges associated with IUDSs and calls for more robust mathematical models in the research space.
Greenhouse Gases from Wastewater Treatment—A review of modelling tools **Mannina et al., 2016**	This paper finds that facility-level, mechanistic, dynamic models are the most comprehensible and reliable tools for quantifying GHGs in wastewater. Detailed mechanisms for N_2O generation across the sector are yet to be established. The paper also highlights the largest contributors of GHGs in the wastewater management process.
Greenhouse Gas Emissions From Wastewater Treatment Plants And By-Product Operations – A Comprehensive Review **Ritter and Chitikela, 2014**	GHG estimates specific to wastewater treatment and resource recovery facilities based on size and type of treatment train, Includes information on electric and natural gas usage presence of sludge anaerobic digestion, biogas-to-energy, and biosolid disposal practices.

References

Brown and Caldwell (2010), Evaluation of Combined Heat and Power Technologies for Wastewater Treatment Facilities: http://water.epa.gov/scitech/wastetech/publications.cfm

California Department of Water Resources (2015), Urban Water Management Plans Guidebook for Urban Water Suppliers: https://water.ca.gov/LegacyFiles/urbanwatermanagement/docs/2015/UWMP_Guidebook_Mar_2016_FINAL.pdf

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