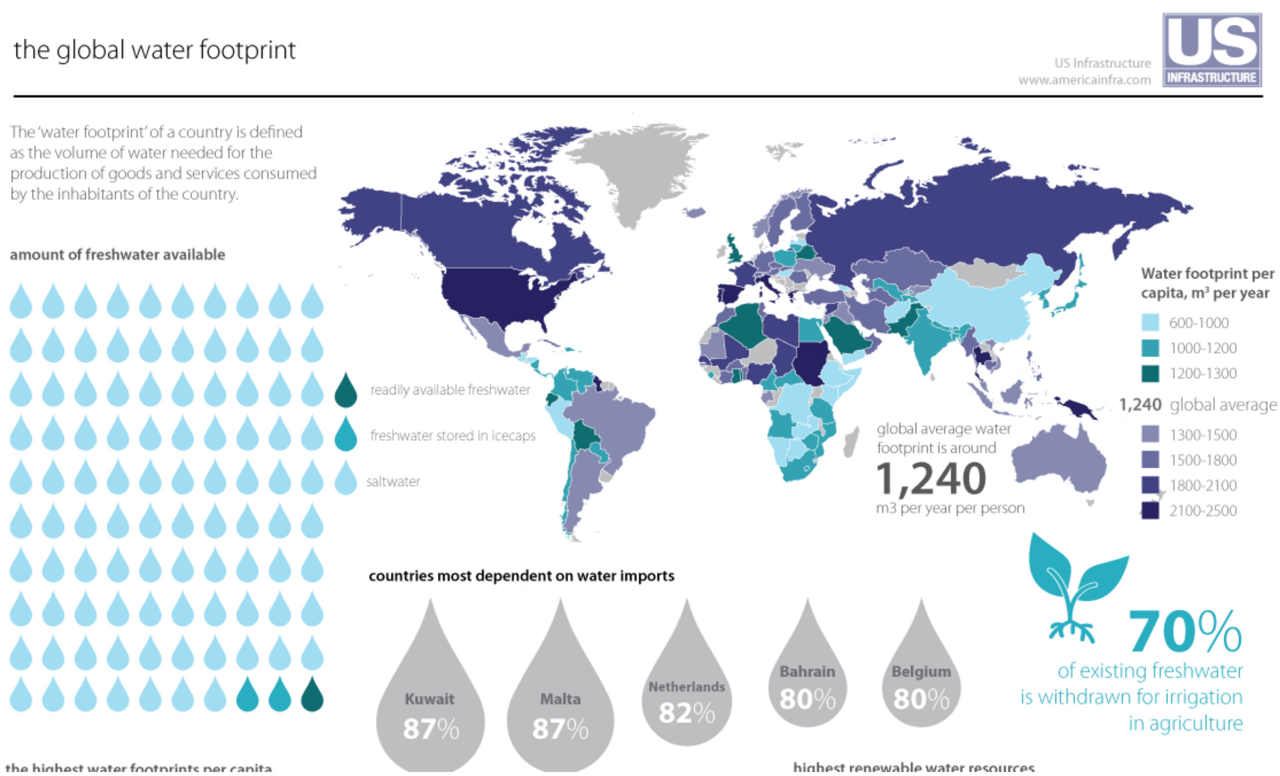
RECLAMATION

Managing Water in the West

The Value of Water: Scoping a Research of Analysis



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U.S. Department of the Interior
Bureau of Reclamation
Phoenix Area Office

Final Report - May 2014

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

WATER RESEARCH FOUNDATION STUDY 4443
UNITED STATES BUREAU OF RECLAMATION

PHASE 1- PROOF OF CONCEPT: USING LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE FOR QUANTIFYING EMBEDDED WATER/ENERGY IN A WATER TREATMENT SYSTEM

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TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY 1
1.0 PROJECT BACKGROUND AND OBJECTIVE 1
2.0 TASK 1 - BOUNDARY, GOAL, AND SCOPE OF WATER TREATMENT ASSEMBLY 2
3.0 TASK 2 - LITERATURE REVIEW, METHODOLOGY DESCRIPTION, AND RELATED RESEARCH 4
3.1 LCA Methodology 4
3.2 LCA Tools 6
3.2.1 SimaPro LCA Software 6
3.2.2 GaBi LCA Software 6
3.2.3 LCI Database 7
3.2.4 LCIA Methodology 8
3.3 LCA Database Data Gap for Water/Wastewater Industry LCA Applications 8
3.4 Related Research 9
3.5 Summary 11
4.0 TASK 3 - LIFE CYCLE INVENTORY TEMPLATE 11
4.1 Life Cycle Inventory Database 11
4.2 Life Cycle Inventory Template 12
4.3 Dynamic Life Cycle Inventory 14
5.0 LIFE CYCLE IMPACT ASSESSMENT 17
6.0 RESULTS AND DISCUSSION 20
6.1 Carbon Emissions Results 26
6.2 Energy Consumption Analysis 29
6.3 Embedded Water Results 30
6.4 Summary Results 33
6.5 Limitations and Data Gaps 33
7.0 TASK 6 - FULL SCALE PLAN OF RESEARCH OUTLINE 34
8.0 REFERENCES 36
9.0 ABBREVIATIONS 38

LIST OF APPENDICES

APPENDIX A LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE DEMONSTRATION
APPENDIX B FUTURE RESEARCH PLAN

LIST OF TABLES

Table ES1 Summary Results ES-3
Table 1 Conceptual Water Treatment Facility Boundary 2
Table 2 Database and LCIA Methods Used in SimaPro and GaBi 7
Table 3 Life Cycle Inventory Template 12
Table 4 LCA Environmental Impacts Associated with Unit Quantity of Material 18
Table 5 Conceptual Case Study Inputs 20
Table 6 Life Cycle Inventory Data 24
Table 7 Breakdown Results for Global Warming 27
Table 8 Operational Phase Energy Consumption versus Embedded Energy (Breakdown by Process) 29
Table 9 Breakdown Results for Embedded Water 31
Table 10 Summary Results 33

LIST OF FIGURES

Figure 1 Phase 1 Study Boundary 2
Figure 2 LCA Inventory Analysis Framework (Vigon et al 1993) 5
Figure 3 Step 1 - Select the Treatment Modules 15
Figure 4 Step 2 - Breakdown Results 16
Figure 5 Step 3 - Review and Customize Design Calculations 16
Figure 6 Global Warming Potential (in g CO_2 equivalent) Breakdown by Process 26
Figure 7 Operational Phase Energy Consumption versus Embedded Energy (Breakdown by Process) 30
Figure 8 Embedded Water (in Liters) Breakdown by Process 30

PHASE 1 - PROOF OF CONCEPT: USING LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE FOR QUANTIFYING EMBEDDED WATER/ENERGY IN A WATER TREATMENT SYSTEM

EXECUTIVE SUMMARY

This research aimed at demonstrating how collecting water infrastructure related life cycle inventory (LCI) data is crucial for life cycle assessment (LCA) and quantification of the environmental impacts (especially embedded water/energy) of a water treatment system.

The fundamental technical approach of the research is based on LCA principles and methodology. LCA is an ISO 14040 normalized method for the environmental assessment of industrial systems from “cradle-to-grave,” which begins with raw materials extracted from the earth, and continues with product development, manufacturing, and disposal (Vince et al. 2008). An LCA study consists of four steps, goal and scope, LCI, life cycle impact assessment (LCIA) and data interpretation. The second step, LCI, is to develop an inventory that contains the quantity of all major inputs and outputs during the entire life cycle of each water treatment process/system within the established boundary. For a water treatment system, this typically includes the raw water being pumped, the product water being delivered, the construction material, consumables, energy and chemical used for each process component during construction and operation, and the quantity of the waste disposal.

Lack of detailed LCI data directly relevant to the widely used water treatment process components and equipment limits the number of embedded water and energy accounting studies and the depth of such studies. Most of the published literatures on LCA for water and wastewater industry remained at a strategic level, aiming at providing guidance and framework for greenhouse gas (GHG) and water footprint assessment. Material and consumable data for water treatment processes is rarely documented in detail. Collecting detailed LCI data for water treatment system is a long-term objective for a subsequent phase of research. To demonstrate how the LCI data can be utilized for assessing embedded water and energy, this initial research phase presented a conceptual study that covers all four steps of an LCA. The study boundary was a theoretical water treatment facility including raw water pumping, coagulation, flocculation, sedimentation, filtration, chlorine disinfection as well as chemicals such as coagulants, acid and liquid chlorine.

An LCI data input template was developed in MS Excel format. This template was used to gather LCI data for the treatment process components within the conceptual case study boundary. Conventionally, the step for filling in this type of LCI template is a time-consuming challenge for water treatment related LCA studies. Users need to collect mechanical equipment and construction materials (e.g., concrete, steel, aluminum, plastics, wood, etc.) used for building each treatment process, as well as consumable material (e.g. filter media), chemicals (e.g., ferric chloride, alum sulfate, sodium hypochlorite), and energy usage during the operation phase of the facility life span.

To improve the efficiencies for the data collection, the data collected in the MS Excel spreadsheet was organized in a module approach. The LCI data was linked to common design calculations. This spreadsheet allowed the user to select or deselect the treatment modules to customize a conceptual water treatment facility. It also allowed quick adjustment of key assumptions (e.g., the unit process capacity, as length of life cycle, unit power costs, and redundancy requirements) and critical design criteria (e.g., surface loading rate, side water depth, retention time, chemical dosage, and power efficiency) for each treatment process. This resulted in a dynamic LCI database that can be easily customized to cover a wide range flow capacity, types, sizes, and preferences.

The study also established environmental impact data for each inventory items. The quantitative measures of impacts were collected from Ecoinvent database. The environmental impacts were normalized to unit quantity of materials, equipment, chemicals, and energy, such as embedded water in one cubic yard of concrete, one pound of steel, one pound or gallon of 12 percent sodium hypochlorite, etc.

By summing the products of the quantity of each inventory item multiplying the corresponding unit quantity inventory environmental impact, the total environmental impacts for a water treatment process and facility can be quickly assessed. The conceptual case study results and a quick guide of how to use this spreadsheet were provided in Appendix A.

The proposed research demonstrated the use of the LCI data for assessing the embedded carbon dioxide emission, embedded energy and embedded water associated with the conceptual water treatment facility. Table ES1 summarizes the results.

It was determined that to produce 1,000 liters of finished water, the 10-million gallon per day (mgd) conceptual water treatment facility emits 211 gram carbon dioxide equivalent (g CO_2 eq), and consumes 0.08 kWh (during the operational phase) and approximately 10 liters of embedded natural water resources. It suggested that the operational phase contributions (energy for raw water pumping and chemical usage) dominate the overall emission of CO_2. The capital (concrete and equipment) produces less than 20 percent contribution to global warming. Similarly, the operational phase contribution dominates the intake of water resource. The capital components produce less than 5 percent contribution to embedded water. The operating phase energy consumption takes up less than 30 percent of the total energy. The embedded energy associated with the production of chemicals, energy and equipment represents more than 70 percent of the total energy consumed. The spreadsheet database also provides breakdown analysis to allow assessment by individual inventory items (e.g., material, energy) or by individual processes. For example, 95+ percent of the energy used for raw water pumping is consumed during the operational phase. However, 95+ percent of the energy used for chemical facilities is embedded energy, consumed prior to the chemical used at the water treatment facility. This conceptual case study demonstrated application potential of the proposed LCI data and methodology. It also identified data gaps to be filled in and future research needs.

Table ES1 Summary Results
Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

Impact Category	Operational Phase Electricity	Global Warming Contributed by Operational Phase Power	Embedded Global Warming	Global Warming	Embedded Water
Unit	**kWh**	**g CO_2 eq**	**g CO_2 eq**	**g CO_2 eq**	**liters**
Entire Water Treatment Facility	2.19E+07	1.64E+10	4.20E+10	5.83E+10	2.80E+09
Total per 1,000 gallons of Water Produced	2.99E-01	2.24E+02	5.75E+02	7.99E+02	3.84E+01
Total per 1,000 liters of Water Produced	7.91E-02	5.92E+01	1.52E+02	2.11E+02	1.01E+01

Note:
Based on 10-mgd water treatment facility, producing 7.30E+10 gallons of water or 2.76E+11 liters of water on a 20-year life cycle. Not all components are included in the study boundary.

PHASE 1 - PROOF OF CONCEPT: USING LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE FOR QUANTIFYING EMBEDDED WATER/ENERGY IN A WATER TREATMENT SYSTEM

1.0 PROJECT BACKGROUND AND OBJECTIVE

Paradoxically, water is our most precious, most wasted, and most undervalued resource. Often due to a lack of understanding, the American public takes for granted that water flows on command where and when it is needed. Centrally distributed water is a commercial product produced by water utilities. Similar to other commercial products such as beef, coffee, hamburger, or milk, water claims commitments of water and other natural resources embedded in the infrastructure and operation of the water conveyance, treatment, and distribution systems. Producing and delivering water from sources with various water qualities consumes commercial products such as energy, equipment, instruments, and chemicals, each of which contains embedded water or removes locally available water from consideration for other uses.

The primary objective of the proposed research is to establish a methodology and framework for collecting and utilizing useful data for assessing the environmental impacts (specifically quantifying the embedded water/energy) of a water treatment system. This research aims at improving the efficiency of assessing such environmental impacts using the existing methodology and resources. It allows water utilities and research partners to quickly assess the water and carbon embedded in the water treatment infrastructures, establishing a foundation for making informed, environmentally responsible decisions. It offers opportunities to raise awareness of the true value of water by accounting for the embedded volume of freshwater and natural resources used to produce the centrally distributed water as a product measured over the full supply chain.

As demonstrated in this project, the use of life cycle inventory data and life cycle impact assessment database offers an efficient approach for assessing the embedded freshwater and carbon emissions for water treatment facilities. This demonstration identifies application potential, data gaps, and future research for the proposed research concept.

The following six main tasks were included in the Phase 1 study. Findings of each task are documented in the following sections.

- Task 1: Boundary, Goal, and Scope of Water Treatment Assembly
- Task 2: Literature Review, Methodology Description, and Data Gap Assessment
- Task 3: Data Collection Template
- Task 4: Life Cycle Impact Assessment

- Task 5: Final Report: Summary of Findings
- Task 6: Full Scale Plan of Research Outline

2.0 TASK 1 - BOUNDARY, GOAL, AND SCOPE OF WATER TREATMENT ASSEMBLY

To demonstrate how the proposed approach can be used to efficiently account for the embedded water and energy in the water treatment infrastructure, a conceptual conventional water treatment facility was established as the study boundary for this Phase in Task 1. The conceptual water treatment facility included the following basic process components for a conventional water treatment plant:

- Raw water pumping
- Coagulation and flocculation
- Sedimentation
- Filtration
- Disinfection
- Chemical storage and feed system

Figure 1 illustrates the study boundary. Descriptions of each process component are shown in Table 1. More detailed process inputs can be found in Appendix A: Life Cycle Inventory and Life Cycle Impact Assessment Database Demonstration.

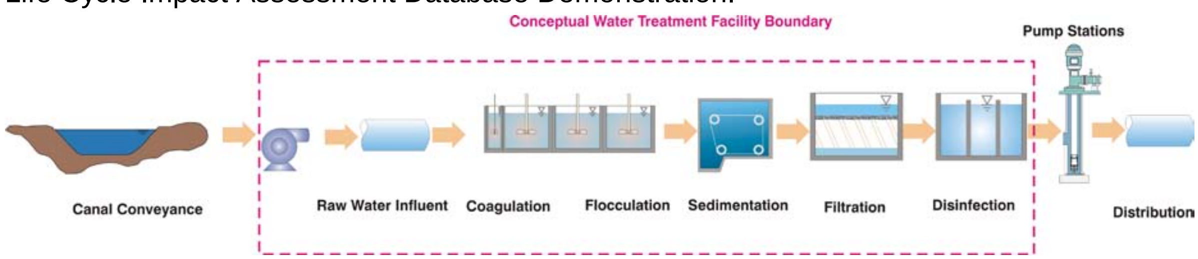

Figure 1 Phase 1 Study Boundary

Table 1 Conceptual Water Treatment Facility Boundary Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System		
Parameters	**Units**	**Value**
Plant Flow	mgd	0-80, adjustable
Life Cycle	yr	20, adjustable
Unit Cost for Electricity	$/kWh	0.08, adjustable
Raw Water Pumping		
Pump Station Wet Well Retention Time	min	60, adjustable

Table 1 Conceptual Water Treatment Facility Boundary Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

Parameters	Units	Value
Coagulation and Flocculation		
Type of Rapid Mix		Concrete basins
G Value	1/s	500, adjustable
Rapid Mix Retention Time	min	1, adjustable
Side Water Depth	ft	14, adjustable
Stage of Flocculator		3, adjustable
Stage 1 G	1/s	35, adjustable
Stage 2 G	1/s	21, adjustable
Stage 3 G	1/s	10, adjustable
Sedimentation		
Type of Sedimentation Tank Options		circular or rectangular concrete basin
Surface Loading Rate	gpm/sf	0.72, adjustable
Sedimentation Basins Retention Time	min	120, adjustable
Filtration		
Surface Loading Rate	gpm/sf	6, adjustable
Side Water Depth	ft	18, adjustable
Depth of Media		
Anthracite	in	24, adjustable
Sand	in	12, adjustable
Gravel	in	6, adjustable
Design Backwash Surface Loading Rate	gpm/sf	20, adjustable
Chlorine Contact Basin		
Chlorine Contact Basin Retention Time	min	30, adjustable
Type of Rapid Mix		Concrete basins
G Value	1/s	500, adjustable
Chemical Storage and Feed – Alum		
Type of Chemicals		Alum 50%
Dosage	mg/L	40, adjustable
Design Storage	day	30, adjustable
Chemical Storage and Feed – Sulfuric Acid		
Type of Chemicals		Sulfuric Acid 93%
Dosage	mg/L	20, adjustable
Design Storage	day	30, adjustable
Chemical Storage and Feed – Sodium Hypochlorite		
Type of Chemicals		Sodium Hypochlorite 12.5%
Dosage	mg/L	5, adjustable
Design Storage	day	30, adjustable

The components considered in the study included:

- Primary construction material consumed to construct the water treatment facility (e.g., concrete, steel, FRP, etc.)
- Electrical power required for operating the mechanical equipment (pumps, mixers, blowers, etc.)
- Process chemical storage and feed
- Waste flows (e.g., disposal of filter media)
- Embedded environmental impacts (water and energy) associated with each material, energy, and chemical items used to build the treatment structures and process trains

The following are NOT included in the Phase 1 study, but may be addressed in the future phases:

- Residuals handling
- Raw water storage and conveyance (e.g., canal, reservoir)
- Finished water distribution
- Site work and excavation, pavement, yard piping, miscellaneous process piping, instruments, administration building, maintenance facilities, electrical buildings and substations, control rooms, security systems, and HVAC
- The indoor/outdoor illumination and other building electricity
- Use of standby power

3.0 TASK 2 - LITERATURE REVIEW, METHODOLOGY DESCRIPTION, AND RELATED RESEARCH

This section presented a brief literature review related to this research. The review focused on the following three aspects:

- Life cycle assessment methodologies used for this study
- Available LCA tools that are similar to what was used for this study
- Limitations and data gaps in the available database

3.1 LCA Methodology

The proposed approach for assessing embedded water and energy utilizes LCA principles and methodology. LCA is a technique for assessing the environmental aspects and potential impacts associated with a product or system (Curran 1996). The LCA method was first described by the Society for Environmental Toxicology and Chemistry (SETAC) (SETAC 1991; SETAC 1993) and refined by the EPA in 1993 (EPA 1993). Then LCA was formalized by the International Organization of Standardization (ISO) 14040: Principles and Framework and ISO 14044: Requirements and Guidelines.

LCA is an ISO 14040 normalized method for the environmental assessment of industrial systems from “cradle-to-grave,” which begins with raw materials extracted from the earth, and continues with product development, manufacturing, and disposal (Vince et al. 2008). LCA considers all energy and environmental implications of processes through the entire life cycle, including design, planning, material extraction and production, manufacturing or construction, use, maintenance, and end-of-life fate of the product (reuse, recycling, incineration, or land filling) (American National Standard Institution 1997). In addition, LCA allows comparison between different schemes providing the same service or function. The general categories of environmental impacts under consideration include resource use, human health, and ecological consequences. LCA can assist in decision-making, improving the environmental aspects of products and selection of relevant indicators of environmental performance.

Figure 2 presents the LCA framework (Vigon et al. 1993 and Vigon and Harrison 1994). Process-based LCA requires data collection from various companies, government agencies, and published studies to evaluate the inputs and outputs of the system.

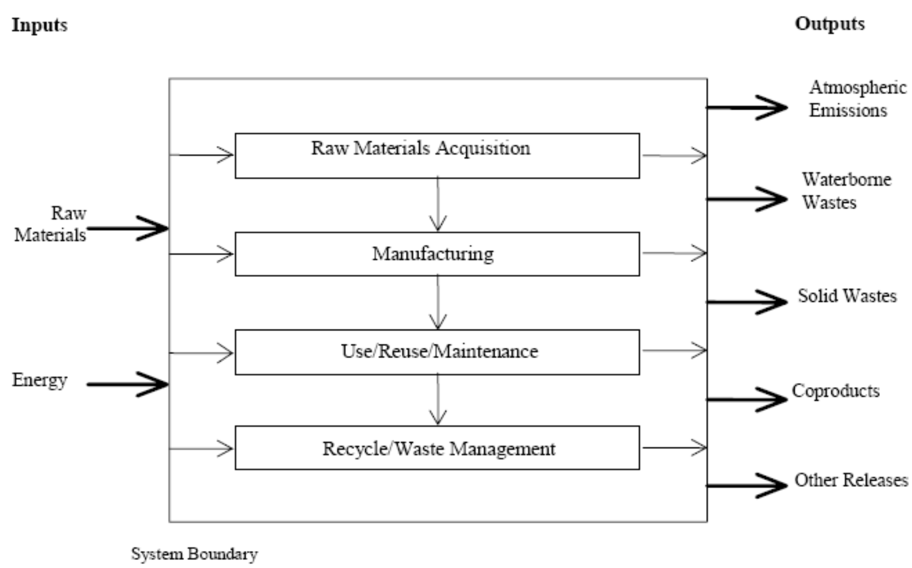

Figure 2 LCA Inventory Analysis Framework (Vigon et al 1993)

An LCA study consists of four steps:

1. Defining the goal and scope of the study.
2. Making a model of the product life cycle with all the environmental inflows and outflows. This data collection effort is usually referred to as the life cycle inventory (LCI) stage.
3. Understanding the environmental relevance of all the inflows and outflows. This is referred to as the life cycle impact assessment (LCIA) phase.
4. Interpreting the study.

3.2 LCA Tools

A number of tools are available for environmental impact assessment. Most of these tools were developed to assess the environmental impact of industrial products. Very few of them have been used for impact assessment of municipal water and wastewater facilities. The most commonly used life cycle assessment tools for the water industry include SimaPro and GaBi.

3.2.1 SimaPro LCA Software

SimaPro is a commercial LCA software tool made according to the ISO standard to facilitate the LCA analysis by PRé Consultants, Netherlands. SimaPro 7.2.0 (PRé Consultants 2004 and 2007) was used to analyze the contribution of the life cycle stages to the overall environmental load produced by the treatment systems. SimaPro includes a large database, including Ecoinvent database, containing a number of processes and several impact assessment methods allowing life cycle analysis of complex systems in an organized way. The updated SimaPro include US based databases such as USA input output database 98 and Franklin USA98. The impact analysis model included in SimaPro contains the TRACI (developed by US Environmental Protection Agency) and the BEES (developed by the National Institute of Standard and Technology) as well as other European based methods. Due to the large amount of uncertainty associated with the geographic and technological factors, these database and impact analysis methods allow a more accurate analysis of the environmental performance of the system in the North America. Instead of giving much focus on long, detailed, and expensive studies, this software allows simplified analysis within a reasonable time. It is successfully used by several researchers to perform LCA of water/wastewater supply and treatment technologies (Ortiz et al. 2007; Lassaux et al. 2007). Although it started as a processed based LCA tool, the new version of SimaPro included the EIO-LCA database. Therefore, EIO-LCA was used to fill in the gaps when process data was not available.

3.2.2 GaBi LCA Software

GaBi is another commonly used commercial LCA software made by PE International, Germany. It was first released in 1993. The software is designed to provide services to perform life cycle assessment, life cycle engineering, technology benchmarking/system analysis, energy efficiency analysis, greenhouse gas accounting, and environmental management systems and sustainability reporting. Similar to SimaPro, Gabi also allows user to build scenarios (called plans in GaBi) and bench mark and compare the environmental impacts of different scenarios. The software is built on Gabi LCA databases, integrated with the Swiss based Ecoinvent LCI database. GaBi has been successfully used in LCA studies, such as by Vince et al. (2008) performing environmental assessment compared different potable water supply systems.

Table 2 below summarizes the databases and LCIA methods used in SimaPro and GaBi.

Table 2 Database and LCIA Methods Used in SimaPro and GaBi Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

	Databases	LCIA Methods
SimaPro	Ecoinvent, US LCI, ELCD, US Input Output, EU and Danish Input Output, Dutch Input Output, LCA Food	ReCiPe, Eco-indicator 99, USEtox, IPCC 2007, EPD, Impact 2002+, CML-IA, Traci 2, BEES, Ecological Footprint EDIP 2003, Ecological scarcity 2006, EPS 2000, Greenhouse Gas Protocol and others
GaBi	GaBi Databases, Ecoinvent, U.S. LCI	CML 2011 – version Dec 2007, Nov 2009, Nov 2010, CML 1996, Eco-Indicator 95, Eco-Indicator 95 RF, Eco-Indicator 99, EDIP 1997, EDIP 2003, Impact 2002+, Method of Ecological Scarcity (UBP Method), ReCiPe, TRACI 2.0, USEtox
Reference	http://www.pre-sustainability.com/databases	http://www.gabi-software.com/international/databases
Note: See Abbreviation List for acronyms.		

3.2.3 LCI Database

This study utilizes the European based Ecoinvent and US based US LCI database. They represent the most widely used LCA databases by the published water treatment system LCA studies. Data gaps identified when using these databases to develop the life cycle inventory for the conceptual water treatment facility accurately reflect the real limitations of the best available data. A brief description of these LCI databases is provided as follows.

The Ecoinvent database is a Swiss based commercial database, one of the world's leading LCI database products. It provides access to unit processes as well as cradle-to-grave inventories covering different industrial areas. Ecoinvent contains international industrial life cycle inventory data on energy supply, resource extraction, material supply, chemicals, metals, agriculture, waste management services, and transport services. Ecoinvent is compatible with and commonly used by all major LCA software tools.

US life cycle inventory (LCI) database is a publically available LCI database, created by NREL and its partners, to help answer questions about environmental impacts. This database maintains data quality, covers commonly used materials, products, and processes in the U.S. with up-to-date, critically reviewed LCI data. This database is a collection of unit processes. It provides a cradle-to-grave accounting of the energy and material flows into and out of the environment that are associated with producing a material, component, or assembly, covering commonly used materials, products, and processes. The critically reviewed LCI data are consistent with a common research protocol and with international standards. The LCI data support efforts to develop product LCA, support systems, and LCA tools. The use of the database requires registration for access.

3.2.4 LCIA Methodology

Among the several impact assessment methods incorporated in SimaPro and GaBi, Building for Environmental and Economic Sustainability [BEES] was used for this study. The selection of this commonly used LCIA method satisfies the purpose of this study, i.e., demonstrating the utility of the LCI data without focusing on the LCIA.

The BEES method was developed by the National Institute of Standards and Technology as a systematic methodology for selecting building products that achieve the most appropriate balance between environment and economics. It is an online web application open to public access. BEES Online measures the environmental performance of building products by using the life cycle assessment approach specified in the ISO 14040 series of standards. All stages in the life of a product are analyzed: raw material acquisition, manufacture, transportation, installation, use, and recycling and waste management. Online application is user friendly, but the content is limited to building construction material.

3.3 LCA Database Data Gap for Water/Wastewater Industry LCA Applications

With the available software and database, the important challenge for LCA application in the field of water and wastewater industry is that several processes, equipment, and chemicals commonly used in water/wastewater treatment are not directly included in existing databases and may require time-consuming steps for raw data gathering, assembling, and analysis. This sets a barrier for the water/wastewater utilities to use LCA in embedded water and energy assessment in sustainability evaluation.

The following items are exemplary water treatment components that are not readily available in the current LCA databases covering materials, manufacturing process, transportation and end of use disposal of the product.

- Readily available data such as quantity take-off of construction material (concrete, steel, etc.) consumed for a commonly used water treatment unit processes with a given capacity (e.g., a 10-mgd coagulation tank, a 1-mgd granular media filter, or a 10-million gallon [MG] reservoir).
- Data of major treatment equipment such as UV lamp for disinfection, centrifuges, gravity belt thickener, and belt filter press for sludge thickening and dewatering.
- Data of miscellaneous equipment for water and wastewater treatment process, such as strainers and mixers.
- Data of common facility structure components, such as aluminum basin covers, and other widely used units such as above ground chemical storage totes and tanks, even though the material (aluminum, high density polyethylene [HDPE] or fiber-reinforced plastic [FRP]) are in the database.
- Data for equipment related to filtration process, including:
  - Cartridge filters (polypropylene type) for membrane pre-filtration.

  - Membrane materials commonly used in water and wastewater treatment such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), and electrodialysis (ED) membranes.
  - Membrane element housing.
  - Filter media, such as anthracite for sand filters and fabric for cloth media filters.
- Data of chemicals commonly used in water and wastewater processes at various bulk concentrations, such as sulfuric acid, phosphonate type antiscalant, acrylamide polymers.

Some of these data gaps can be filled by engineers and designers through reviewing typical treatment facility design documents. Others may take additional level of data collection efforts and require participation from industry partners such as equipment manufacturers and trade organizations. These gaps set forth the target for the proposed LCI data collection in future research phases.

3.4 Related Research

The literature review findings on the topic of water and energy embedded in water/wastewater industry that are directly related to this study are summarized in the following section.

Bonton et al. (2012) conducted a study comparing life cycle assessment of two water treatment plants: an empirical modeled (conceptual-designed) conventional granular activated carbon (GAC) plant and an existing nanofiltration plant located in the province of Quebec, Canada that has been in operation for over 10 years. This study used SimaPro software version 7.3 for life cycle inventory and impact assessment. The Ecoinvent 2.0 database was chosen for the inventory analysis of inputs (resources, energy) and outputs (emissions) of each chemical and materials process. Energy resources included in Ecoinvent 2.0 were replaced by local energy resources depending on the location of the manufactured product (US energy or Quebec hydro-electricity energy).This study performed detailed LCA comparison for these two plants based on equal feed (raw surface freshwater) and treated water qualities. The study revealed that among the phases of construction, operation, and decommissioning, the operation phase has the highest potential environmental impacts. It also indicated that the conventional-GAC plant has greater impacts than the NF plant, caused by the use of coal-based GAC treatment, based on the fact that hydroelectricity is a dominant power source. Corrosion control chemicals (carbon dioxide, calcium hydroxide, and sulfuric acid) in a distribution system using pH and alkalinity adjustments have significant environmental impacts. The study developed life cycle inventory for NF treatment plant. The main building components (wall, insulation, foundation, etc.) and treatment components (pre-filters, pipes, tanks, etc.) were considered in the inventory. For membrane elements, it included PVC membrane housing and spiral wound membrane module stowage (assumed to be PVC instead of the actual material).

Vince et al. (2008) compared different potable water supply systems (groundwater treatment, ultrafiltration, nanofiltration, seawater reverse osmosis, and thermal distillation) using LCA.

They used Gabi 4.2 software and IMPACT 2002+ method to assess the impact assessment results. The data collection relies on specifically developed models ("LCA modeling") for water treatment steps and on the Ecoinvent database for the other industrial processes such as chemicals and electricity production. The results showed that the electricity was the main source of environmental impacts. Thermal desalination, membrane treatment processes, and ozone production were identified to be "the most energy intensive treatment steps seconded with chemicals production for coagulant and remineralization."

The Engineering Research Center (ERC) for Re-inventing the Nation's Urban Water Infrastructure (ReNUWIt) as an interdisciplinary, multi-institution research center, aims "to facilitate the transition of water systems to a new state in which they consume less energy and resources while continuing to meet the needs of urban users and aquatic ecosystems". One of the ReNUWIt outreach goals is to develop breakthrough modular technologies and novel system-level approaches to substantially reduce energy use and related GHGs emissions in water conveyance, treatment, distribution, and reuse. The ERC Year I annual report (2012) included LCA under U-thrust efforts (urban systems integration and institutions) U4 theme (life cycle assessment of urban water infrastructure), intended to quantify energy, GHGs, toxic emissions, and waste production in the evaluation of new technologies. The goal under the U-thrust is to use LCA principles to "assess comprehensive life-cycle environmental costs in decision making related to urban water infrastructure." This effort will extend previous research on LCA for urban water infrastructure by developing a comprehensive set of environmental, economic, and social metrics as well as complete LCA models related to complex water systems, including their supply chains.

The best literature relevant to the proposed study was the Water-Energy Sustainability Tool (WEST) and Wastewater-Energy Sustainability Tool (WWEST). WEST and WWEST are MS Excel-based tools, established and currently in progress of development by Arpad Horvath and Jennifer Stokes at University of California, Berkeley. WEST is developed to determine the environmental effects of water system infrastructure and operation (Stokes and Horvath 2006), considering up to five water sources and process design scenarios. WWEST evaluates each wastewater treatment scenario separately. Based on the material and energy inputs for the facility construction and operation phases, the model provides output for life cycle air emissions. These efforts included LCI data collection for the water and wastewater treatment systems.

Several case studies were conducted using WEST. Stokes and Horvath (2009) used WEST to evaluate the life cycle assessment of water systems. Four water sources (imported water, seawater desalination, brackish groundwater desalination, and recycled water) were analyzed in southern California. Seawater desalination was reported to be 1.5 to 2.4 times more environmentally intensive than imported water and brackish groundwater. Since energy is the dominant factor for environmental impacts, different alternatives of energy production were discussed. Later in 2011, the researchers used WEST in a California case study utility and concluded that energy production, followed by chemical production, are the most significant activities contributing to water supply's energy needs and emissions.

3.5 Summary

In summary, within the few literatures that have been published on water/energy LCA applied in water and wastewater industry, most of the reference literatures are at a strategic level, aiming at providing guidance and framework for GHG and water footprint assessment. Most of these studies utilized available LCA databases (such as Ecoinvent) to develop the life cycle inventory for the water treatment components. Detailed quantification of material and consumables for the water treatment system were rarely developed and documented for these studies. The best literature relevant to the proposed study was the WEST tool by Stokes and Horvath, which included LCI data collection for water and wastewater treatment components (e.g., pipeline, equipment, solids disposal, etc.).

The primary focus of the proposed research is to outline an approach that could be further developed through subsequent research to develop LCI data that are relevant to the water treatment system. Through gathering in-depth engineering data on material use and equipment design for common water infrastructure, the proposed research could produce useful data sets that can be used in LCA tools such as SimaPro, GaBi or WEST. Collaborating with researchers developing these tools and the relevant LCA database is critical in future phases.

4.0 TASK 3 - LIFE CYCLE INVENTORY TEMPLATE

After defining the boundaries, the goal and the scope, the next step of the life cycle assessment was to develop a life cycle inventory that contains the quantity of all major inputs and outputs during the entire life cycle of each process/system within the established boundary. For this study, the LCI included the amount of water being pumped and treated, the product water being delivered, the construction material, consumables, energy and chemicals used for each process component during construction and operation, and the quantity of the waste disposal.

4.1 Life Cycle Inventory Database

In the inventory phase, a model was made of the complex technical system that is used to produce, transport, use, and dispose a product. This resulted in a flow sheet or process tree with all the relevant processes. For each process, all the relevant inflows and the outflows were collected.

Essentially, the process inputs could be divided into environmental input (raw materials and energy resources, say raw water pumped from the canal, etc.) and economic input (products, semi-finished products or energy from technosphere - say steel, concrete, chemicals etc.). Similarly, process outputs could be divided into environmental output (emissions to water, air and soil - say carbon dioxide, etc.) and economic output (product/co-product, or semi-finished product or energy to other processes in the technosphere - say the finished water, etc.). The creation of the LCI does not have to iterative until all inputs and outputs are exhaustively listed, considering all contributions in the entire life cycle of a product from mining, processing, transportation to consumption and final disposal. The LCA databases containing same or similar processes/products are used to fill in the economic inputs down in the supply chain and reduce the data collection burden. For example, when the LCA modeler includes concrete in the LCI, the database will automatically include all raw materials and energy resources consumed during the production and transportation of concrete.

4.2 Life Cycle Inventory Template

One of the main subtasks of Task 3 is to establish an input data template in MS Excel format. This inventory template quantitatively identified the energy and material consumption throughout the life cycle of the water treatment system within the study boundary. Each unit process was set up in a separate worksheet using a modular approach. In each modular worksheet, the following inventory data were derived from the design calculations:

- Raw and product water in million gallons per day (mgd) or gallons per minute (gpm)
- Construction materials, such as concrete, steel, aluminum, plastics, wood, etc. in pounds of material (lb) or cubic yard of volume (cy)
- Consumable material during the facility operation, such as filter media, etc. in pounds of material (lb)
- Chemical usage, such as ferric chloride, alum sulfate, sodium hypochlorite, etc. in pounds of chemical (lb)
- Electrical energy usage during operation of the facility life span, in kW
- Mechanical equipment in US dollar value ($)

The Phase 1 template is limited to the components to assemble a water treatment facility defined in the Phase 1 study boundary. These items are included in this phase to illustrate how the proposed approach works to account for the embedded energy and water. The list could be expanded in a future phase to cover more types of material, process, energy, and wastes. Table 3 shows an example of the input data collection template.

Table 3 Life Cycle Inventory Template
Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

Select Process	Select Capacity	mgd
Impact Category	**Quantity**	**Material Unit**
Mechanical/Equipment		
Pumps and compressors		USD
Blowers and fans		USD
Measuring and dispensing pumps		USD
Pipe, valves, and pipe fittings		USD
Materials		
Gravel		kg

Table 3	**Life Cycle Inventory Template Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System**	
Select Process	Select Capacity	mgd
Impact Category	**Quantity**	**Material Unit**
Sand		kg
Hard coal mix, at regional storage		kg
Concrete (reinforced)		kg
Concrete, normal		m^3
Brick		kg
Polyvinylchloride, suspension polymerized		kg
PVC pipe		kg
Polyethylene, HDPE, granulate		kg
HDPE pipes		kg
Glass fiber reinforced plastic, polyester resin, hand lay-up		kg
St13 I - Material		kg
Reinforcing steel		kg
Steel product manufacturing, average metal working		kg
Copper I - Material		kg
Copper product manufacturing, average metal working		kg
Aluminum, production mix		kg
Aluminum product manufacturing		kg
Chemicals		
Sodium hydroxide, 50% in H_2O, production mix		kg
Sodium hypochlorite, 15% in H_2O		kg
Lime, hydrated, packed		kg
Quicklime, milled, packed		kg
Sulfuric acid, liquid		kg
Hydrochloric acid, from the reaction of hydrogen with chlorine		kg
Hydrochloric acid, 30% in H_2O		kg
Phosphoric acid, industrial grade, 85% in H_2O		kg
Aluminum sulfate, powder		kg
Iron (III) chloride, 40% in H_2O		kg
Ammonium sulfate, as N, at regional storehouse		kg
Energy		
Electricity, high voltage, at grid		kWh
Natural gas, at consumer		MJ

4.3 Dynamic Life Cycle Inventory

The inventory templates were filled for each of the water treatment processes included in the study boundary. The following eight filled life cycle inventory templates were developed during the Phase 1 study.

- Raw Water Pumping
- Chemical: Alum
- Chemical: Sulfuric
- Coagulation Flocculation
- Sedimentation
- Filtration
- Chemical: Sodium Hypochlorite
- Chlorine Contact Basin

The steps for filling in this template represent a time-consuming challenge for water treatment related LCA studies. The LCA researchers or the water utilities interested in assessing the environmental impacts associated with the water treatment processes have to collect treatment capacities, chemical dosage, energy consumption, basin sizes, thickness of concrete walls, quantity of rebar, etc. and convert the quantities of material and energy into the required format. To improve the efficiencies for the data collection, the proposed approach links the inventory data to common design calculations.

The templates are incorporated into a MS Excel database file. The spreadsheet allows the user to select or deselect the treatment modules to build a customized conceptual water treatment facility. It allows adjustment of the unit process capacity (in million gallons per day) and automatically recalculates the associated environmental impacts. It includes detailed design calculations with default design criteria (e.g., surface loading rate, side water depth, retention time, chemical dosage, power efficiency) and other assumptions (e.g., length of life cycle, unit power costs, redundancy requirements) that are kept adjustable. By keeping the inventory linked with adjustable design calculations, each of these filled templates represents a dynamic database that can be quickly customized to cover a wide range flow capacity, types, sizes, preferences, etc.

These sheets as well as the design calculations and a detailed guide on how to use the spreadsheet can be found in Appendix A. The raw excel spreadsheet file is also attached to this report.

To customize the inventory database, users need to follow a few simple steps.

Step 1: Select the Treatment Modules

- Illustrated in Figure 3.
- By clicking on the checkboxes located on the "Main" workbook, users can select or deselect appropriate modules to assemble their own treatment facility. When selecting or deselecting the checkboxes, workbooks named in corresponding modules will appear or disappear from the workbook.
- Adjust the plant flow input in the blue cell to the desired treatment capacity (e.g., 10 mgd). The current database is limited to 0 - 80 mgd. This range can be expanded in future phases.
- Review default length of life cycle (20 years) and unit cost for electricity ($0.08/kWh). Adjust if necessary.
- Once the user completes Step 1 inputs, the total environmental impacts (embedded energy and water) associated with the selected treatment facility is updated in a table below the input area. These values are expressed in gram of carbon dioxide equivalent for global warming and liters of embedded water.

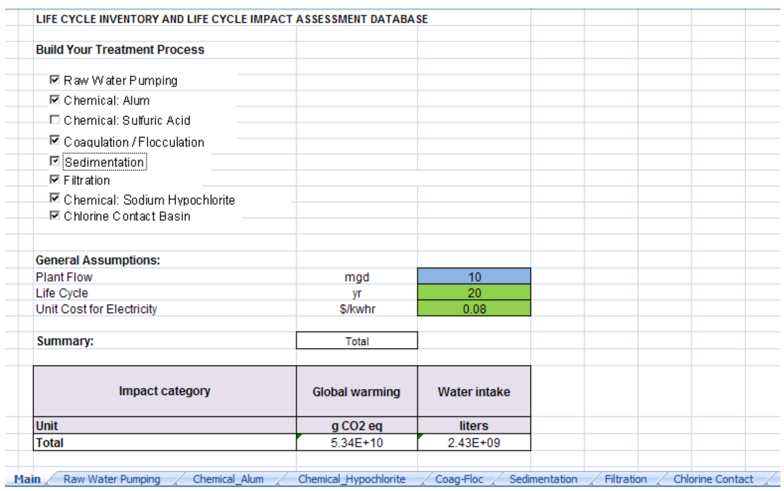

Figure 3 Step 1 - Select the Treatment Modules

Step 2: Breakdown Results

- Illustrated in Figure 4.
- Besides the total gram of carbon dioxide equivalent and liters of embedded water, users can review more detailed results by clicking on ungroup buttons to expand hidden rows and columns. These results include:
  - Contribution of environmental impacts broken down by material and energy inventory.
  - Results for 11 more impact categories such as ozone depletion potential, acidification, etc. besides global warming and embedded water.

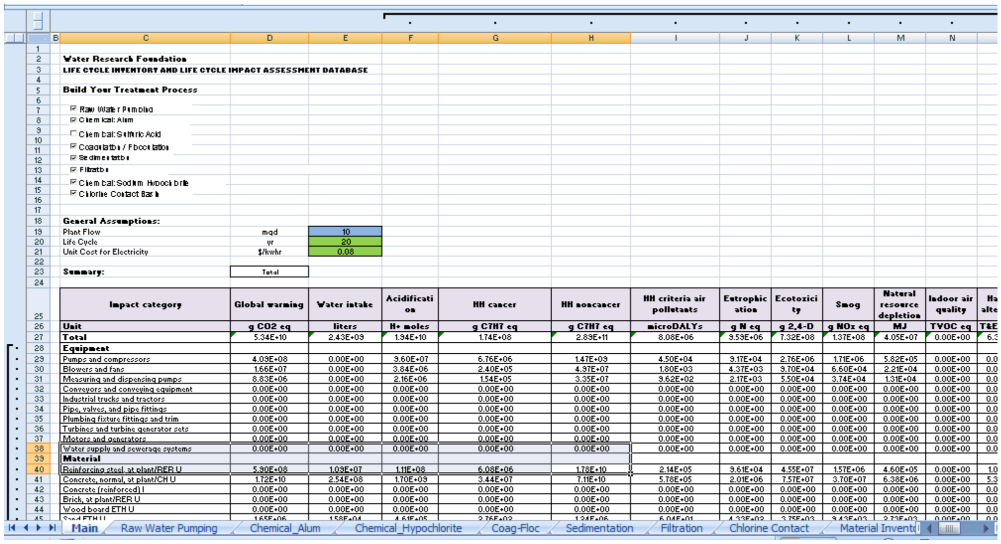

Figure 4 Step 2 - Breakdown Results

Step 3: Review and Customize Design Calculations

- Illustrated in Figure 5, user can choose to review each of the workbooks corresponding to the selected treatment modules.
- User's input cells are color coded in blue and recommended default design criteria in green. Follow the color coding to enter and adjust inputs as necessary.
- When making changes to the design calculations, the life cycle inventory data on the bottom of each modular workbook is updated automatically.

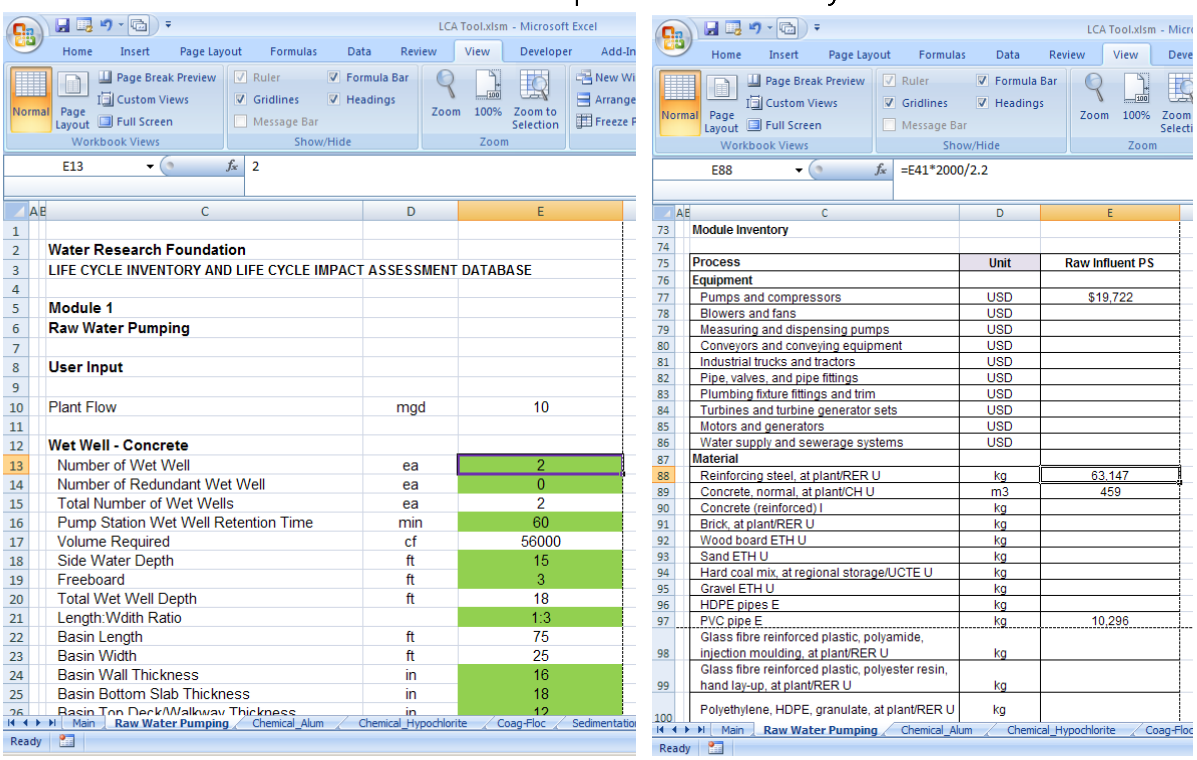

Figure 5 Step 3 - Review and Customize Design Calculations
(Left: Design Calculation Example; Right: Module Inventory Database Example)

5.0 LIFE CYCLE IMPACT ASSESSMENT

Task 4 of the study established a quantitative environmental impact package for the inventory established in Task 3. For the Phase 1 study, the quantitative measures of impacts were collected from readily available sources, i.e., Ecoinvent database, the same data used in SimaPro. The environmental impacts were normalized to unit quantity of materials, equipment, chemicals, and energy, such as embedded water in one cubic yard of concrete, one pound of steel, one pound or gallon of 12 percent sodium hypochlorite, etc. The unit environmental impacts were then summarized into the same MS Excel database file developed in Task 4. The impacts examined in this study will mainly focus on embedded water and carbon emissions during the facility construction and operation. It also includes other impact categories that are commonly evaluated in a typical LCA analysis, such as ozone depletion and smog. Table 4 presents the results of the environmental impacts for unit quantity of material and energy.

Table 4 LCA Environmental Impacts Associated with Unit Quantity of Material
Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

Impact Category	Quantity	Material Unit	Global Warming	Acidification	HH Cancer	HH Noncancer	HH Criteria Air Pollutants	Eutrophication	Ecotoxicity	Smog	Natural Resource Depletion	Indoor Air Quality	Habitat Alteration	Embedded Water	Ozone Depletion
Impact Unit			CO_2 eq	H+ moles eq	C7H7 eq	C7H7 eq	microDALYs	N eq	2,4-D eq	NOx eq	MJ surplus	TVOC eq	T&E count	liters	CFC-11 eq
Mechanical/Equipment															
Pumps and compressors	1	USD	8.05E+02	1.89E+02	1.33E+01	2.89E+03	8.86E-02	1.80E-01	5.42E+00	3.37E+00	1.15E+00	0.00E+00	0.00E+00	0.00E+00	1.62E-03
Blowers and fans	1	USD	8.93E+02	2.07E+02	1.29E+01	2.67E+03	9.66E-02	2.35E-01	5.22E+00	3.55E+00	1.19E+00	0.00E+00	0.00E+00	0.00E+00	1.45E-03
Measuring and dispensing pumps	1	USD	8.83E+02	2.16E+02	1.54E+01	3.35E+03	9.62E-02	2.17E-01	5.50E+00	3.74E+00	1.31E+00	0.00E+00	0.00E+00	0.00E+00	1.93E-03
Pipe, valves, and pipe fittings	1	USD	1.06E+03	2.55E+02	1.73E+01	6.58E+03	1.26E-01	2.19E-01	6.25E+00	4.06E+00	1.35E+00	0.00E+00	0.00E+00	0.00E+00	6.14E-03
Materials															
Gravel	1	kg	1.02E+01	2.87E+00	2.02E-03	8.41E+00	3.92E-04	2.66E-03	2.53E-02	5.64E-02	1.64E-02	0.00E+00	0.00E+00	1.12E-01	9.95E-06
Sand	1	kg	9.73E+00	2.72E+00	1.63E-03	7.32E+00	3.55E-04	2.55E-03	2.21E-02	5.55E-02	1.60E-02	0.00E+00	0.00E+00	9.31E-02	9.85E-06
Hard coal mix, at regional storage	1	kg	2.68E+02	8.22E+01	1.40E-01	2.63E+03	1.38E-01	7.15E-02	4.62E-01	1.35E+00	4.72E-01	0.00E+00	3.73E-14	3.46E+00	5.34E-06
Concrete (reinforced)	1	kg	1.07E+02	4.01E+01	6.89E+00	9.26E+03	6.68E-03	2.85E-02	4.28E-01	7.94E-01	1.87E-01	0.00E+00	0.00E+00	1.92E+00	8.84E-07
Concrete, normal	1	m^3	2.59E+05	2.56E+04	5.19E+02	1.07E+06	8.73E+00	3.04E+01	1.14E+03	5.58E+02	9.63E+01	0.00E+00	8.06E-13	3.83E+03	6.37E-03
Brick	1	kg	2.12E+02	3.15E+01	6.73E-02	7.62E+01	8.10E-03	3.43E-02	2.42E-01	5.88E-01	3.28E-01	0.00E+00	1.40E-16	1.21E+00	4.09E-06
Polyvinylchloride, suspension polymerised	1	kg	1.89E+03	2.87E+02	1.71E+00	5.54E+03	7.92E-02	4.66E-01	2.57E+01	4.87E+00	6.40E+00	0.00E+00	1.09E-15	4.64E+02	1.21E-07
PVC pipe	1	kg	3.18E+03	7.42E+02	5.32E+02	6.77E+05	2.61E-01	9.62E-01	3.90E+01	9.79E+00	0.00E+00	0.00E+00	0.00E+00	7.43E+01	0.00E+00
Polyethylene, HDPE, granulate, at plant	1	kg	1.90E+03	3.40E+02	9.69E-01	1.74E+02	1.10E-01	1.61E-01	6.43E-01	4.11E+00	1.01E+01	0.00E+00	7.86E-16	3.22E+01	9.37E-08
HDPE pipes	1	kg	2.44E+03	5.01E+02	7.15E-01	8.68E+01	1.63E-01	2.15E-01	1.12E+00	1.04E+01	0.00E+00	0.00E+00	0.00E+00	4.65E+01	0.00E+00
Glass fiber reinforced plastic, polyester resin, hand lay-up	1	kg	4.67E+03	8.88E+02	6.36E+01	3.34E+04	3.27E-01	4.68E+00	3.53E+01	1.11E+01	8.84E+00	0.00E+00	1.34E-14	1.57E+02	3.80E-04
St13 I - Material	1	kg	1.00E+03	5.27E+02	1.72E+02	2.31E+05	9.32E-02	2.70E-01	9.57E+00	8.87E+00	8.46E-01	0.00E+00	0.00E+00	1.18E+00	2.93E-06
Reinforcing steel, at plant	1	kg	1.40E+03	2.64E+02	1.44E+01	4.21E+04	5.09E-01	2.28E-01	1.08E+02	3.73E+00	1.09E+00	0.00E+00	2.49E-14	2.58E+01	2.17E-05
Steel product manufacturing, average metal working	1	kg	1.79E+03	3.08E+02	8.23E+00	1.77E+04	2.39E-01	8.82E-01	3.29E+01	3.91E+00	2.07E+00	0.00E+00	5.66E-14	5.25E+01	6.39E-05
Copper I - Material	1	kg	7.51E+03	3.52E+04	1.29E-02	1.42E+01	9.42E+00	1.09E+00	6.28E-01	3.11E+01	1.25E+01	0.00E+00	0.00E+00	1.26E-01	2.92E-07
Copper product manufacturing, average metal working	1	kg	1.80E+03	1.66E+03	1.45E+02	3.07E+05	8.02E-01	1.21E+00	5.28E+01	8.56E+00	2.27E+00	0.00E+00	7.42E-13	6.18E+01	7.44E-05
Aluminum, production mix, at plant - Material	1	kg	7.77E+03	1.88E+03	3.29E+01	2.22E+04	1.43E+00	1.68E+00	3.13E+01	1.66E+01	7.99E+00	0.00E+00	8.57E-14	2.03E+02	3.03E-04
Aluminum product manufacturing, average metal working - Processing	1	kg	3.17E+03	6.47E+02	1.08E+01	9.71E+03	4.07E-01	1.18E+00	1.48E+01	6.44E+00	3.57E+00	0.00E+00	2.47E-14	9.11E+01	1.27E-04

Table 4 LCA Environmental Impacts Associated with Unit Quantity of Material
Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

Impact Category	Quantity	Material Unit	Global Warming	Acidification	HH Cancer	HH Noncancer	HH Criteria Air Pollutants	Eutrophication	Ecotoxicity	Smog	Natural Resource Depletion	Indoor Air Quality	Habitat Alteration	Embedded Water	Ozone Depletion
Impact Unit			CO_2 eq	H+ moles eq	C7H7 eq	C7H7 eq	microDALYs	N eq	2,4-D eq	NOx eq	MJ surplus	TVOC eq	T&E count	liters	CFC-11 eq
Chemicals															
Sodium hydroxide, 50% in H_2O, production mix	1	kg	1.01E+03	2.36E+02	1.21E+00	1.50E+04	9.72E-02	2.93E-01	7.71E+01	2.16E+00	8.96E-01	0.00E+00	7.46E-15	1.13E+02	2.78E-05
Sodium hypochlorite, 15% in H_2O	1	kg	7.63E+02	1.74E+02	8.30E-01	8.72E+03	7.19E-02	2.15E-01	4.37E+01	1.90E+00	8.71E-01	0.00E+00	4.77E-15	6.50E+01	2.35E-05
Lime, hydrated, packed	1	kg	7.57E+02	3.77E+01	3.54E-01	7.76E+02	2.48E-02	4.24E-02	3.42E-01	6.33E-01	5.19E-01	0.00E+00	9.25E-17	2.30E+00	4.30E-05
Quicklime, milled, packed	1	kg	9.82E+02	4.85E+01	3.89E-01	9.37E+02	3.21E-02	5.32E-02	4.35E-01	8.14E-01	6.73E-01	0.00E+00	1.14E-16	2.04E+00	5.58E-05
Sulfuric acid, liquid	1	kg	8.60E+01	6.75E+02	1.04E-01	1.64E+02	1.82E-01	6.29E-02	3.67E-01	8.42E-01	1.54E-01	0.00E+00	1.46E-16	5.07E+01	7.71E-06
Hydrochloric acid, from the reaction of hydrogen with chlorine	1	kg	1.17E+03	2.75E+02	3.15E+00	1.50E+04	1.12E-01	3.11E-01	7.66E+01	2.53E+00	1.27E+00	0.00E+00	8.09E-15	1.18E+02	2.44E-03
Hydrochloric acid, 30% in H_2O	1	kg	7.35E+02	1.82E+02	1.77E+00	7.83E+03	7.20E-02	2.87E-01	3.91E+01	1.61E+00	8.79E-01	0.00E+00	5.04E-15	7.25E+01	1.23E-03
Phosphoric acid, industrial grade, 85% in H_2O	1	kg	1.21E+03	1.67E+03	3.14E+01	7.13E+03	6.57E-01	1.06E+02	6.46E+00	4.16E+00	1.79E+00	0.00E+00	2.93E-14	1.56E+02	5.92E-05
Aluminum sulfate, powder	1	kg	4.58E+02	4.44E+02	3.25E+00	1.40E+03	2.02E-01	1.29E-01	3.68E+00	1.65E+00	5.59E-01	0.00E+00	6.50E-15	3.89E+01	2.04E-05
Iron (III) chloride, 40% in H_2O	1	kg	6.17E+02	1.50E+02	1.87E+00	1.29E+04	6.08E-02	1.90E-01	6.69E+01	1.46E+00	5.64E-01	0.00E+00	4.49E-15	6.38E+01	1.53E-03
Ammonium sulfate, as N	1	kg	2.37E+03	3.45E+02	1.22E+00	3.02E+03	1.51E-01	3.45E-01	4.64E+00	3.84E+00	5.56E+00	0.00E+00	3.50E-15	7.71E+00	6.05E-05
Energy															
Electricity, high voltage	1	kWh	7.48E+02	2.64E+02	1.53E+00	2.62E+03	8.97E-02	9.43E-02	1.93E+00	1.74E+00	5.04E-01	0.00E+00	1.72E-14	2.67E+01	4.71E-06
Natural gas, at consumer	1	MJ	1.32E+01	2.83E+01	3.34E-01	3.89E+02	7.76E-03	3.66E-03	8.95E-02	2.48E-02	1.81E-01	0.00E+00	2.21E-17	3.44E-02	1.09E-08

6.0 RESULTS AND DISCUSSION

By summing the product of each inventory item and the corresponding unit quantity inventory environmental impact, the total environmental impacts for a water treatment process and facility can be quickly assessed. A conceptual case study was assessed using the proposed approach. Table 5 summarizes the key inputs for this case study. Table 6 summarizes the life cycle inventory calculated from the parameters in Table 5. More details can be found in Appendix A.

Table 5 Conceptual Case Study Inputs
Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

Parameters	Units	Value
Plant Flow	mgd	10
Life Cycle	yr	20
Unit Cost for Electricity	$/kWh	0.08
Water Treated on Life Cycle	gallons	7.30E+10
Raw Water Pumping		
Pump Station Wet Well Retention Time	min	60
Total Number of Wet Wells	ea	2 + 0
Basin Length	ft	75
Basin Width	ft	25
Total Wet Well Depth	ft	18
Total Number of Pumps	ea	2+1
Flow per Pump	mgd	5
TDH	ft	50
Break Horsepower (BHP)	HP	44
Efficiency	%	75
Motor Efficiency	%	95
VFD Efficiency	%	98
Motor Size	HP	63
Online Factor	%	100%
Power Consumption	kWh/year	820,000
Pipe Length	ft	500
Maximum Design Velocity	fps	8
Chemical: Alum		
Type of Chemicals		Alum 50%
Dosage	mg/L	40
Design Storage	day	30
Total Number of Storage Tank	ea	2

Table 5 Conceptual Case Study Inputs Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System		
Parameters	**Units**	**Value**
Chemical Tank Diameter	ft	12
Chemical Tank Height (excluding freeboard)	ft	11
Chemical Storage Tank Volume	gallons	10,000
Chemical Storage Tank Material		Fiberglass
Total Number of Metering Pumps	ea	1+1
Misc Equipment Size	HP	0.2
Chemical: Sulfuric Acid		
Type of Chemicals		Sulfuric Acid 93%
Dosage	mg/L	20
Design Storage	day	30
Total Number of Storage Tank	ea	2
Chemical Tank Diameter	ft	12
Chemical Tank Height (excluding freeboard)	ft	2
Chemical Storage Tank Volume	gallons	2000
Chemical Storage Tank Material		Fiberglass
Total Number of Metering Pumps	ea	1+1
Misc Equipment Size	HP	0.2
Coagulation Flocculation		
Total Number of Rapid Mix	ea	2
Rapid Mix Retention Time	min	1
Total Rapid Mix Depth	ft	16
Basin Length	ft	8
Basin Width	ft	8
Total Number of Mixers	ea	1+1
G Value	1/s	500
Break Horsepower (BHP)	HP	8
Efficiency		0.65
Motor Efficiency		0.95
Motor Size	HP	12
Online Factor	%	100%
Power Consumption	kWh/year	80494
Type of Flocculation Tank		Vertical, 3-Stage, Concrete
Total Number of Flocculation Tank	ea	1+1
Flocculation Tank Retention Time	min	30
Total Flocculation Tank Depth	ft	16
Basin Length	ft	77
Basin Width	ft	26

Table 5	**Conceptual Case Study Inputs Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System**	
Parameters	**Units**	**Value**
Total Number of Flocculators	ea	1+1
Stage 1 G	1/s	35
Stage 2 G	1/s	21
Stage 3 G	1/s	10
Sedimentation		
Total Number of Sedimentation Basins	ea	1+1
Sedimentation Basins Retention Time	min	120
Surface Loading Rate	gpm/sf	0.72
Side Water Depth	ft	14
Freeboard	ft	2
Total Sedimentation Basin Depth	ft	16
Total Number of Scrapper	ea	1+1
Sedimentation - Concrete Rectangular		
Basin Length	ft	100
Basin Width	ft	100
Sedimentation - Concrete Circular		
Basin Diameter	ft	111
Filtration		
Type of Filter Box		Rectangular Concrete
Type of Filter Media		Dual Media
Total Number of Filters	ea	4+1
Surface Loading Rate	gpm/sf	6
Side Water Depth	ft	18
Freeboard	ft	2
Total Filter Depth	ft	20
Basin Length	ft	25
Basin Width	ft	13
Type of Media		Dual Media
Depth of Media		
Anthracite	in	24
Sand	in	12
Gravel	in	6
Chemical: Sodium Hypochlorite		
Type of Chemicals		Sodium Hypochlorite 12.5%
Dosage	mg/L	5
Design Storage	day	30
Total Number of Storage Tank	ea	2

Table 5 Conceptual Case Study Inputs
Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

Parameters	Units	Value
Chemical Storage Tank Volume	gallons	5000
Chemical Storage Tank Material		Fiberglass
Total Number of Metering Pumps	ea	1+1
Miscellaneous Equipment Size	HP	0.2
Chlorine Contact Basin		
Type of Chlorine Contact Basin		Rectangular Concrete
Total Number of Chlorine Contact Basin	ea	1+1
Chlorine Contact Basin Retention Time	min	30
Side Water Depth	ft	14
Freeboard	ft	2
Total Chlorine Contact Basin Depth	ft	16
Basin Length	ft	45
Basin Width	ft	45
Total Number of Rapid Mix	ea	2
Rapid Mix Retention Time	min	0.5
Total Rapid Mix Depth	ft	16
Basin Length	ft	6
Basin Width	ft	6
Total Number of Mixers	ea	1+1
G Value	1/s	500
Break Horsepower (BHP)	HP	4
Efficiency		0.65
Motor Efficiency		0.95
Motor Size	HP	6
Power Consumption	kWh/year	40,680

Table 6 Life Cycle Inventory Data
Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

	Unit	1	1	1	1	1	1	1	1	
Process		**Raw Water Pumping**	**Chemical_Alum**	**Chemical_Sulfuric**	**Coagulation**	**Sedimentation**	**Filtration**	**Chemical_Hypo**	**Chlorine Contact**	**Total**
Equipment										
Pumps and Compressors	USD	1.97E+04	0.00E+00	0.00E+00	2.54E+05	1.90E+05	1.24E+04	0.00E+00	3.20E+04	5.08E+05
Blowers and Fans	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.86E+04	0.00E+00	0.00E+00	1.86E+04
Measuring and Dispensing Pumps	USD	0.00E+00	5.00E+03	5.00E+03	0.00E+00	0.00E+00	0.00E+00	5.00E+03	0.00E+00	1.50E+04
Conveyors and Conveying Equipment	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Industrial Trucks and Tractors	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pipe, Valves, and Pipe Fittings	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plumbing Fixture Fittings and Trim	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turbines and Turbine Generator Sets	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Motors and Generators	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water Supply and Sewerage Systems	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Material										
Reinforcing Steel	kg	6.31E+04	3.21E+00	1.30E+00	5.87E+04	1.57E+05	3.38E+04	2.02E+00	1.09E+05	4.21E+05
Concrete, Normal	m^3	4.59E+02	3.85E+04	1.62E+04	4.80E+02	1.23E+03	2.66E+02	2.46E+04	7.53E+02	8.24E+04
Concrete (Reinforced)	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Brick	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wood Board	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sand	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E+05	0.00E+00	0.00E+00	1.70E+05
Hard Coal Mix, at Regional Storage	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.48E+05	0.00E+00	0.00E+00	1.48E+05
Gravel	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.39E+04	0.00E+00	0.00E+00	7.39E+04
HDPE pipes	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.26E+05	0.00E+00	0.00E+00	1.26E+05
PVC pipe	kg	1.03E+04	0.00E+00	0.00E+00	2.06E+03	2.06E+03	4.12E+03	0.00E+00	2.06E+03	2.06E+04
Glass Fiber Reinforced Plastic, Polyamide, Injection Molding	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Glass Fiber Reinforced Plastic, Polyester Resin, Hand Lay-Up	kg	0.00E+00	3.18E+03	6.36E+02	0.00E+00	8.37E+03	2.71E+03	1.59E+03	0.00E+00	1.65E+04
Polyethylene, HDPE, Granulate	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
St13 I - Material	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper I - Material	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper Product Manufacturing, Average Metal Working	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminum, Production Mix - Material	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminum Product Manufacturing, Average Metal Working	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 6 Life Cycle Inventory Data
Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

	Unit	1	1	1	1	1	1	1	1	
Process		**Raw Water Pumping**	**Chemical_Alum**	**Chemical_Sulfuric**	**Coagulation**	**Sedimentation**	**Filtration**	**Chemical_Hypo**	**Chlorine Contact**	**Total**
Chemical										
Sodium Hydroxide, 50% in H_2O, Production Mix	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sodium Hypochlorite, 15% in H_2O	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E+07	0.00E+00	1.11E+07
Lime, Hydrated, Packed	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Quicklime, Milled, Packed	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sulfuric Acid, Liquid	kg	0.00E+00	0.00E+00	5.94E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.94E+06
Aluminum Sulfate, Powder	kg	0.00E+00	2.21E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.21E+07
Iron (III) Chloride, 40% in H_2O	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric Acid, from the Reaction of Hydrogen With Chlorine	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric Acid, 30% in H_2O	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Phosphoric Acid, Industrial Grade, 85% in H_2O	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ammonium Sulfate, as N, at Regional Storehouse	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Energy										
Electricity, High Voltage, at Grid	kWh	1.64E+07	3.14E+05	3.14E+05	2.01E+06	1.06E+06	6.40E+05	3.14E+05	8.14E+05	2.19E+07
Natural Gas, at Consumer	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

6.1 Carbon Emissions Results

Table 7 and Figure 6 present a breakdown analysis of global warming potential expressed in g CO_2 equivalent. It was observed that the operational phase contributions (energy for raw water pumping and chemical usage) dominant the overall emission of CO_2. The capital (concrete and equipment) produces less than 20 percent contributions to global warming. This is consistent with findings by other LCAs that the operation stage instead of the capital usually represents more than 70 percent of the overall impact (Friedrich 2002).

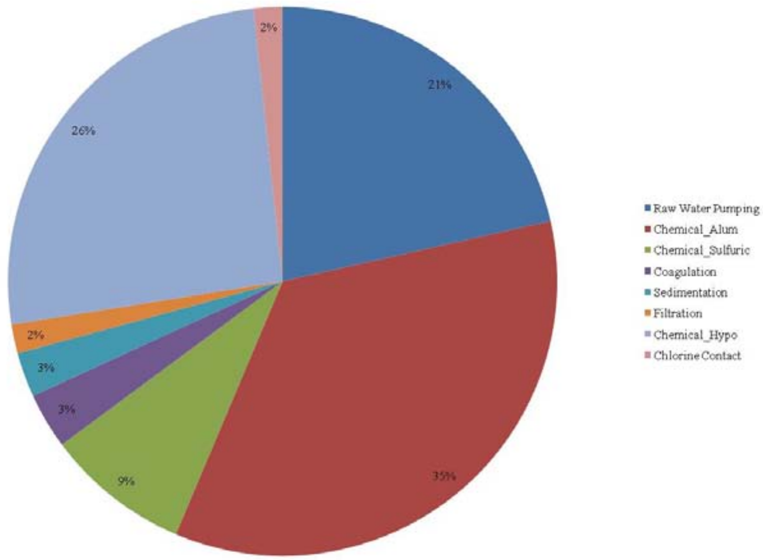

Figure 6 Global Warming Potential (in g CO_2 equivalent) Breakdown by Process

Table 7 Breakdown Results for Global Warming Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System									
Impact Category	**Global warming**								
Unit	**g CO_2 eq**								
	Raw Water Pumping	**Chemical_Alum**	**Chemical_Sulfuric**	**Coagulation**	**Sedimentation**	**Filtration**	**Chemical_Hypo**	**Chlorine Contact**	**Total**
Total	**1.25E+10**	**2.03E+10**	**4.96E+09**	**1.92E+09**	**1.53E+09**	**9.97E+08**	**1.51E+10**	**9.89E+08**	**5.83E+10**
Percentage	**21%**	**35%**	**9%**	**3%**	**3%**	**2%**	**26%**	**2%**	**100%**
Equipment									
Pumps and compressors	1.59E+07	0.00E+00	0.00E+00	2.04E+08	1.53E+08	9.97E+06	0.00E+00	2.57E+07	4.09E+08
Blowers and fans	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.66E+07	0.00E+00	0.00E+00	1.66E+07
Measuring and dispensing pumps	0.00E+00	4.42E+06	4.42E+06	0.00E+00	0.00E+00	0.00E+00	4.42E+06	0.00E+00	1.32E+07
Conveyors and conveying equipment	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Industrial trucks and tractors	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pipe, valves, and pipe fittings	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plumbing fixture fittings and trim	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turbines and turbine generator sets	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Motors and generators	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water supply and sewerage systems	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Material									
Reinforcing steel	8.85E+07	4.50E+03	1.83E+03	8.22E+07	2.20E+08	4.74E+07	2.83E+03	1.53E+08	5.90E+08
Concrete, normal	1.19E+08	9.97E+09	4.20E+09	1.24E+08	3.18E+08	6.90E+07	6.37E+09	1.95E+08	2.14E+10
Concrete (reinforced)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Brick	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wood board	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sand	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.65E+06	0.00E+00	0.00E+00	1.65E+06
Hard coal mix, at regional storage	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.95E+07	0.00E+00	0.00E+00	3.95E+07
Gravel	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.51E+05	0.00E+00	0.00E+00	7.51E+05
HDPE pipes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.07E+08	0.00E+00	0.00E+00	3.07E+08
PVC pipe	3.27E+07	0.00E+00	0.00E+00	6.54E+06	6.54E+06	1.31E+07	0.00E+00	6.54E+06	6.54E+07
Glass fiber reinforced plastic, polyamide, injection molding	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Glass fiber reinforced plastic, polyester resin, hand lay-up	0.00E+00	1.49E+07	2.97E+06	0.00E+00	3.91E+07	1.27E+07	7.43E+06	0.00E+00	7.70E+07
Polyethylene, HDPE, granulate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
St13 I - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper I - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper product manufacturing, average metal working	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminum, production mix - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminum product manufacturing, average metal working	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 7 Breakdown Results for Global Warming
Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

Impact Category	Global warming								
Unit	g CO_2 eq								
	Raw Water Pumping	Chemical_Alum	Chemical_Sulfuric	Coagulation	Sedimentation	Filtration	Chemical_Hypo	Chlorine Contact	Total
Chemical									
Sodium hydroxide, 50% in H_2O, production mix	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sodium hypochlorite, 15% in H_2O	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.44E+09	0.00E+00	8.44E+09
Lime, hydrated, packed	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Quicklime, milled, packed	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sulfuric acid, liquid	0.00E+00	0.00E+00	5.11E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.11E+08
Aluminum sulfate, powder	0.00E+00	1.01E+10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E+10
Iron (III) chloride, 40% in H_2O	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric acid, from the reaction of hydrogen with chlorine	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric acid, 30% in H_2O	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Phosphoric acid, industrial grade, 85% in H_2O	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ammonium sulfate, as N, at regional storehouse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Energy									
Electricity, high voltage, at grid	1.23E+10	2.35E+08	2.35E+08	1.50E+09	7.91E+08	4.79E+08	2.35E+08	6.09E+08	1.64E+10
Natural gas, at consumer	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

6.2 Energy Consumption Analysis

Table 8 and Figure 7 present an analysis of energy consumption operating the treatment facility versus the embedded energy, which is the energy consumed to produce material and product (e.g., chemicals, equipment and energy) used for constructing and operating the water treatment facility. Overall, as illustrated by the “total” process category, the operating phase energy consumption takes up less than 30 percent of the total energy. The embedded energy represents more than 70 percent of the total energy consumed. For raw water pumping category, 95+ percent energy is consumed during the operational phase. However, for chemical facilities, 95+ percent energy is embedded energy, consumed prior to the chemical used at the water treatment facility.

Table 8 Operational Phase Energy Consumption versus Embedded Energy (Breakdown by Process)
Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

Process	Operational Phase Electricity, high voltage, at grid/US U kWh	Global Warming Contributed by Operational Phase Power g CO_2 eq	Embedded Global Warming g CO_2 eq	Total Global Warming g CO_2 eq
Raw Water Pumping	1.64E+07	1.23E+10	2.56E+08	1.25E+10
Chemical_Alum	3.14E+05	2.35E+08	2.01E+10	2.03E+10
Chemical_Sulfuric	3.14E+05	2.35E+08	4.72E+09	4.96E+09
Coagulation	2.01E+06	1.50E+09	4.18E+08	1.92E+09
Sedimentation	1.06E+06	7.91E+08	7.36E+08	1.53E+09
Filtration	6.40E+05	4.79E+08	5.18E+08	9.97E+08
Chemical_Hypo	3.14E+05	2.35E+08	1.48E+10	1.51E+10
Chlorine Contact	8.14E+05	6.09E+08	3.80E+08	9.89E+08
Total	**2.19E+07**	**1.64E+10**	**4.20E+10**	**5.83E+10**

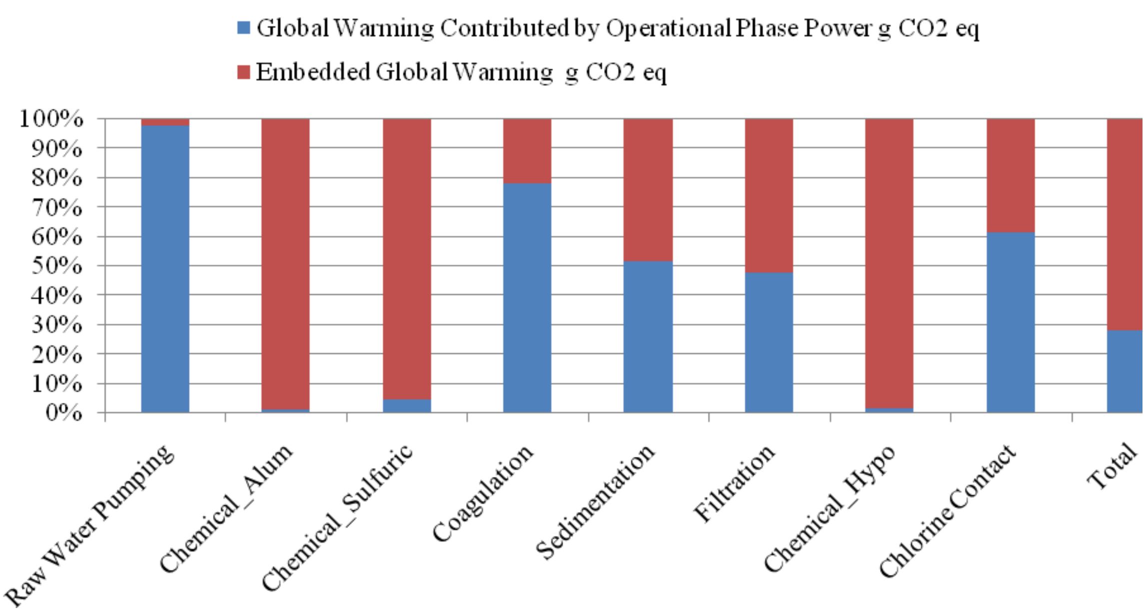

Figure 7 Operational Phase Energy Consumption versus Embedded Energy (Breakdown by Process)

6.3 Embedded Water Results

Table 9 and Figure 8 present a breakdown analysis of embedded water expressed in liters. Similar to the global warming impact, the operational phase contributions (raw water pumping and chemical usage) dominant the intake of water resource. The capital (concrete and equipment) produces less than 5 percent contributions to embedded water. For the purpose of this analysis, the raw water intake to the water treatment facility and the water used on the water treatment plant site was not included. The results represent the embedded water consumed to produce the construction material, chemicals, energy, etc. associated with the conceptual treatment facility on the entire life cycle (i.e., 10 mgd treated water for 20 years).

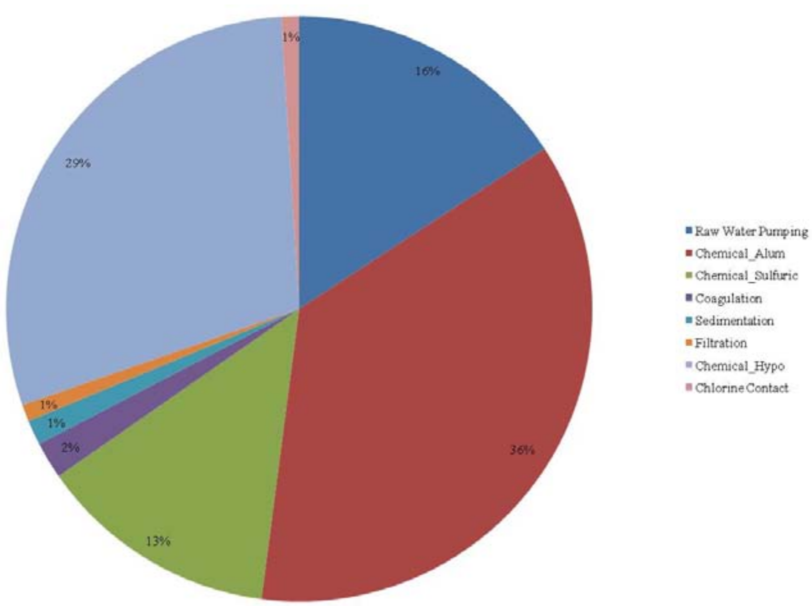

Figure 8 Embedded Water (in Liters) Breakdown by Process

Table 9 Breakdown Results for Embedded Water
Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

Impact Category	Embedded Water								
Unit	liter								
	Raw Water Pumping	Chemical_Alum	Chemical_Sulfuric	Coagulation	Sedimentation	Filtration	Chemical_Hypo	Chlorine Contact	Total
Total	**4.43E+08**	**1.02E+09**	**3.72E+08**	**5.72E+07**	**3.85E+07**	**2.61E+07**	**8.22E+08**	**2.76E+07**	**2.80E+09**
Percentage	**16%**	**36%**	**13%**	**2%**	**1%**	**1%**	**29%**	**1%**	**100%**
Equipment									
Pumps and compressors	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Blowers and fans	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Measuring and dispensing pumps	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Conveyors and conveying equipment	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Industrial trucks and tractors	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pipe, valves, and pipe fittings	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plumbing fixture fittings and trim	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turbines and turbine generator sets	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Motors and generators	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water supply and sewerage systems	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Material									
Reinforcing steel	1.63E+06	8.30E+01	3.37E+01	1.52E+06	4.05E+06	8.73E+05	5.22E+01	2.81E+06	1.09E+07
Concrete, normal	1.76E+06	1.48E+08	6.22E+07	1.84E+06	4.70E+06	1.02E+06	9.42E+07	2.89E+06	3.16E+08
Concrete (reinforced)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Brick	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wood board	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sand	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.58E+04	0.00E+00	0.00E+00	1.58E+04
Hard coal mix, at regional storage	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.12E+05	0.00E+00	0.00E+00	5.12E+05
Gravel	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.28E+03	0.00E+00	0.00E+00	8.28E+03
HDPE pipes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.86E+06	0.00E+00	0.00E+00	5.86E+06
PVC pipe	7.65E+05	0.00E+00	0.00E+00	1.53E+05	1.53E+05	3.06E+05	0.00E+00	1.53E+05	1.53E+06
Glass fiber reinforced plastic, polyamide, injection molding	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Glass fiber reinforced plastic, polyester resin, hand lay-up	0.00E+00	5.00E+05	1.00E+05	0.00E+00	1.32E+06	4.26E+05	2.50E+05	0.00E+00	2.59E+06
Polyethylene, HDPE, granulate	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
St13 I - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper I - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper product manufacturing, average metal working	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminum, production mix - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminum product manufacturing, average metal working	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 9 Breakdown Results for Embedded Water
Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

Impact Category	Embedded Water								
Unit	liter								
	Raw Water Pumping	Chemical_Alum	Chemical_Sulfuric	Coagulation	Sedimentation	Filtration	Chemical_Hypo	Chlorine Contact	Total
Chemical									
Sodium hydroxide, 50% in H_2O, production mix	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sodium hypochlorite, 15% in H_2O	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.19E+08	0.00E+00	7.19E+08
Lime, hydrated, packed	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Quicklime, milled, packed	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sulfuric acid, liquid	0.00E+00	0.00E+00	3.01E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.01E+08
Aluminum sulfate, powder	0.00E+00	8.59E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.59E+08
Iron (III) chloride, 40% in H_2O	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric acid, from the reaction of hydrogen with chlorine	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric acid, 30% in H_2O	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Phosphoric acid, industrial grade, 85% in H_2O	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ammonium sulfate, as N, at regional storehouse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Energy									
Electricity, high voltage, at grid	4.39E+08	8.39E+06	8.39E+06	5.37E+07	2.83E+07	1.71E+07	8.39E+06	2.18E+07	5.85E+08
Natural gas, at consumer	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

6.4 Summary Results

Table 10 presents the carbon emission and embedded water associated with the conceptual water treatment facility. The results are presented in total carbon emission and embedded water for the 10-mgd treatment facility and per 1,000 gallons or 1,000 liters of water produced.

Table 10 Summary Results
Phase 1 - Proof of Concept: Using Life Cycle Inventory and Life Cycle Impact Assessment Database for Quantifying Embedded Water/Energy in a Water Treatment System

Impact Category	Operational Phase Electricity	Global Warming Contributed by Operational Phase Power	Embedded Global Warming	Global Warming	Embedded Water
Unit	**kWh**	**g CO_2 eq**	**g CO_2 eq**	**g CO_2 eq**	**liters**
Entire Water Treatment Facility	2.19E+07	1.64E+10	4.20E+10	5.83E+10	2.80E+09
Total per 1,000 gallons of Water Produced	2.99E-01	2.24E+02	5.75E+02	7.99E+02	3.84E+01
Total per 1,000 liters of Water Produced	7.91E-02	5.92E+01	1.52E+02	2.11E+02	1.01E+01

Note:
Base on 10-mgd water treatment facility, producing 7.30E+10 gallons of water or 2.76E+11 liters of water on a 20-year life cycle.

6.5 Limitations and Data Gaps

Besides the most commonly used construction material such as concrete, steel, aluminum, many other materials used in the water industry may not be easily identified in the existing LCA database. Most LCA studies, including the Phase 1 study of this project, concluded that the capital (material consumption and equipment) usually represents less than 30 percent of the overall impact. Details such as ethylene propylene diene monomer (EPDM) gaskets and rubber liner of a ductile iron resilient wedge gate valve may not produce any significance in the overall evaluation. However, oversimplification may also compromise the accuracy of LCA studies. Future research is recommended to prioritize the data collection efforts and strategically collect typical details that can be commonly used in water treatment LCA.

Ecoinvent database includes several categories for equipment, expressed in US$. These categories include pumps and compressors, blowers and fans, measuring and dispensing pumps, conveyors and conveying equipment, industrial trucks and tractors, pipe, valves, and pipe fittings, plumbing fixture fittings and trim, turbines and turbine generator sets, motors and generators, water supply and sewerage systems, etc. However, this cannot cover all equipment used in the water treatment processes. For example, sludge scrapper, mixer, and flocculator do not fit in any of these categories directly. Moreover, knowing that the categories do not distinguish motor sizes and type of pumps/compressors the data accuracy is questionable.

Without extensive data collection and analysis, it is difficult to account for the weight / quantity of certain materials consumed for a treatment facility component. For example, Ecoinvent database has a few data entry for different type of FRP material, expressed in kg and labeled as “Glass fiber reinforced plastic, polyamide, injection molding” and “Glass fiber reinforced plastic, polyester resin, hand lay-up”. The Phase 1 database took a simplified approach by estimating the weight of the FRP tank after it is sized (e.g., 3,500 lb for a 10,000-gallon tank based on shop drawings for reference projects). Detailed trade knowledge on how an FRP tank is manufactured and how much energy and natural resources are consumed during the manufacturing process should be obtained in future research phases.

Ecoinvent database contains cast iron as a material, but no information on cast iron / ductile iron pipe can be found. The database does include PVC and HDPE pipe, expressed by weight. The spreadsheet developed for this phase of project collected some data (e.g., weight per linear foot) for various pipe sizes and product grade. Such data are often readily available from equipment manufacturers. It is recommended that extensive data collection should be conducted for other piping material in future research phases.

Data of common water facility components, such as aluminum flat or dome covers, handrails, grating, cable tray, FRP water troughs and launders, and chemical storage totes and tanks, lime silos, etc., are not readily available, even though the raw material (aluminum, HDPE or FRP) are included in the Ecoinvent database. Such data gaps could be filled efficiently by collecting data for typical products and trade standards.

Some data of chemicals commonly used in water and wastewater processes are included in the Ecoinvent database, but are limited. For example, the database may have 50 percent caustic soda solution but not have it at 25 percent. By accounting for the energy and water consumption during the chemical batching process, chemical products at various concentrations can be easily modeled with accuracy.

7.0 TASK 6 - FULL SCALE PLAN OF RESEARCH OUTLINE

Task 6 of the study developed a full-scale plan of research outline and define the research questions for the future phase. The full-scale plan aimed to assist decision making on process selections for water treatment, with regard to sustainability values. The research outline covered sections such as research objectives of future phases, expanded study boundaries and level of details, existing and raw data collection, case studies and water treatment alternative evaluation. This document in included in Appendix B: Future Research Plan.

The technical approach for the proposed future studies could potentially consist of the following steps.

- Task 1: Expand the Prototype LCA Data Collection. Determine the high priority data elements (and their numeric value).
- Task 2: Stakeholder Workshop. To get utility input on specific research ideas.
- Task 3: Water Utility Case Studies.
- Task 4: Power Supply Sensitivity Analysis.

The following briefly describes these steps.

Task 1: Expand the Prototype LCA Data Collection

- Expand the prototype LCA data established in Phase 1 of the study. Fill in data gap using available literature references and published database information.
- Update literature review with up-to-date on-going research, applications, opportunities, and challenges related to LCA analysis in the field of water industry.
- Establish a data collection plan.
- Prioritize the data collection efforts.
- Collaborate with industry partners (e.g., equipment manufacturers or professional organizations) to collect raw data for water industry on membrane technologies and advanced oxidation processes.

Task 2: Stakeholder Workshop

- Conduct stakeholder workshop to prioritize the data wish list generated in the Phase 1 study, focusing on the interest of the southwest region of the United States, i.e., reclamation service area.
- Invite reclamation and utilities who are using lesser water quality sources.
- Investigate the opportunities for reclamation and drinking water utilities to integrate the use of LCA analyses into sustainable planning and operations.
- Gather input from water utilities to prioritize the data collection and establish case study areas.

Task 3: Water Utility Case Studies

- Select case study topics gathered at the stakeholder workshop (described in Task 2).
- Identify case study partnership. Set case study boundaries.
- Potential case study # 1: Investigate embedded water and energy associated with three water supply alternatives for central Arizona, including imported water, brackish water desalination, and indirect potable reuse.

- Potential case study # 2: Wastewater Treatment Plant Reclaimed Water Appraisal Study, which evaluates the environmental impacts of using reclaimed water as for other purposes (such as power plant cooling water, wetland restoration, and indirect potable reuse)

<u>Task 4: Power Supply Sensitivity Analysis</u>

- Review current status of renewable energies as power supply alternatives, such as wind, solar, or taking advantage of biogas for power cogeneration in situ.
- Collect renewable energies data based on literature review and available LCA software and database. Investigate opportunities to corporate with NREL and utilize their expertise and knowledge to assist the data collection.
- Conduct sensitivity analysis using LCA results to evaluate environmental impacts generated by various power supply sources.

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9.0 ABBREVIATIONS

BEES	Building for Environmental and Economic Sustainability
CML	Institute of Environmental Sciences
ED	electrodialysis
EPD	Environmental Product Declarations
EPDM	ethylene propylene diene monomer
EPS	Environmental Product Strategies
ELCD	European Reference Life Cycle Database
ERC	Engineering Research Center
FRP	Fiber-Reinforced Plastic
GAC	granular activated carbon
GHG	greenhouse gas
GWRC	Global Water Research Coalition
HDPE	high density polyethylene
IA	impact assessment
IAC	Industrial Assessment Centers
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	life-cycle assessment
LCI	life cycle inventory
LCIA	life cycle inventory assessment
MF	microfiltration
NF	nanofiltration
NREL	National Renewable Energy Laboratory
ReNUWIt	Re-inventing the Nation's Urban Water Infrastructure
ReCiPe	LCIA method attempting to combine midpoint and endpoint impact assessments
RO	reverse osmosis
SETAC	Society for Environmental Toxicology and Chemistry
Traci	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
UBP	Method of Ecological Scarcity
UF	ultrafiltration
UKWIR	UK Water Industry Research
USEPA	United States Environmental Protection Agency
UNEP	united nations environment programme
USEtox	UNEP-SETAC toxicity model
WEST	Water-Energy Sustainability Tool
WWEST	Wastewater-Energy Sustainability Tool

Appendix A

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE DEMONSTRATION

Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

U.S. DEPARTMENT OF THE INTERIOR
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Engineers...Working Wonders With Water™

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LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Carbon Analysis Water Analysis Energy Analysis LCI Database Summary

☑ Raw Water Pumping
☑ Chemical: Alum
☑ Chemical: Sulfuric Acid
☑ Coagulation / Flocculation
☑ Sedimentation
☑ Filtration
☑ Chemical: Sodium Hypochlorite
☑ Chlorine Contact Basin

General Assumptions:

Plant Capacity	mgd	10
Life Cycle	yr	20
Unit Cost for Electricity	$/kwhr	0.08
Water Produced on Life Cycle	gallons	7.30E+10
Water Produced on Life Cycle	liters	2.76E+11

* check online factor on indvidual input sheets

Summary: Entire Facility

Impact category	Global warming	Water intake
Unit	**g CO2 eq**	**liters**
Total	5.83E+10	2.80E+09
Total per 1000 gallons of Water Produced	7.99E+02	3.84E+01
Total per 1000 liters of Water Produced	2.11E+02	1.01E+01
Equipment		
Pumps and compressors	4.09E+08	0.00E+00
Blowers and fans	1.66E+07	0.00E+00
Measuring and dispensing pumps	1.32E+07	0.00E+00
Conveyors and conveying equipment	0.00E+00	0.00E+00
Industrial trucks and tractors	0.00E+00	0.00E+00
Pipe, valves, and pipe fittings	0.00E+00	0.00E+00
Plumbing fixture fittings and trim	0.00E+00	0.00E+00
Turbines and turbine generator sets	0.00E+00	0.00E+00
Motors and generators	0.00E+00	0.00E+00
Water supply and sewerage systems	0.00E+00	0.00E+00
Material		
Reinforcing steel, at plant/RER U	5.86E+08	1.08E+07
Concrete, normal, at plant/CH U	2.14E+10	3.16E+08
Concrete (reinforced) I	0.00E+00	0.00E+00
Brick, at plant/RER U	0.00E+00	0.00E+00
Wood board ETH U	0.00E+00	0.00E+00
Sand ETH U	1.65E+06	1.58E+04
Hard coal mix, at regional storage/UCTE U	3.95E+07	5.12E+05
Gravel ETH U	7.51E+05	8.28E+03
HDPE pipes E	3.07E+08	5.86E+06
PVC pipe E	6.54E+07	1.53E+06
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	0.00E+00	0.00E+00
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	7.70E+07	2.59E+06
Polyethylene, HDPE, granulate, at plant/RER U	0.00E+00	0.00E+00
St13 I - Material	0.00E+00	0.00E+00
Copper I - Material	0.00E+00	0.00E+00
Copper product manufacturing, average metal working/RER U	0.00E+00	0.00E+00
Aluminium, production mix, at plant/RER U - Material	0.00E+00	0.00E+00
Aluminium product manufacturing, average metal working/RER U - Processing	0.00E+00	0.00E+00
Chemical		
Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	0.00E+00	0.00E+00
Sodium hypochlorite, 15% in H2O, at plant/RER U	8.44E+09	7.19E+08
Lime, hydrated, packed, at plant/CH U	0.00E+00	0.00E+00
Quicklime, milled, packed, at plant/CH U	0.00E+00	0.00E+00
Sulphuric acid, liquid, at plant/RER U	5.11E+08	3.01E+08
Aluminium sulphate, powder, at plant/RER U	1.01E+10	8.59E+08
Iron (III) chloride, 40% in H2O, at plant/CH U	0.00E+00	0.00E+00
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	0.00E+00	0.00E+00
Hydrochloric acid, 30% in H2O, at plant/RER U	0.00E+00	0.00E+00
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	0.00E+00	0.00E+00
Ammonium sulphate, as N, at regional storehouse/RER U	0.00E+00	0.00E+00
Energy		
Electricity, high voltage, at grid/US U	1.64E+10	5.85E+08
Natural gas, at consumer/RNA U	0.00E+00	0.00E+00

Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Treatment Process Material Inventory

	Unit	1	1	1	1	1	1	1	1	
Process		**Raw Water Pumping**	**Chemical_Alum**	**Chemical_Sulfuric**	**Coagulation**	**Sedimentation**	**Filtration**	**Chemical_Hypo**	**Chlorine Contact**	**Entire Facility**
Equipment										
Pumps and compressors	USD	1.97E+04	0.00E+00	0.00E+00	2.54E+05	1.90E+05	1.24E+04	0.00E+00	3.20E+04	5.08E+05
Blowers and fans	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.86E+04	0.00E+00	0.00E+00	1.86E+04
Measuring and dispensing pumps	USD	0.00E+00	5.00E+03	5.00E+03	0.00E+00	0.00E+00	0.00E+00	5.00E+03	0.00E+00	1.50E+04
Conveyors and conveying equipment	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Industrial trucks and tractors	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pipe, valves, and pipe fittings	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plumbing fixture fittings and trim	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turbines and turbine generator sets	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Motors and generators	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water supply and sewerage systems	USD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Material										
Reinforcing steel, at plant/RER U	kg	6.13E+04	3.21E+00	1.30E+00	5.87E+04	1.57E+05	3.23E+04	2.02E+00	1.09E+05	4.18E+05
Concrete, normal, at plant/CH U	m3	4.32E+02	3.85E+04	1.62E+04	4.80E+02	1.23E+03	2.57E+02	2.46E+04	7.53E+02	8.24E+04
Concrete (reinforced) I	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Brick, at plant/RER U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wood board ETH U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sand ETH U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E+05	0.00E+00	0.00E+00	1.70E+05
Hard coal mix, at regional storage/UCTE U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.48E+05	0.00E+00	0.00E+00	1.48E+05
Gravel ETH U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.39E+04	0.00E+00	0.00E+00	7.39E+04
HDPE pipes E	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.26E+05	0.00E+00	0.00E+00	1.26E+05
PVC pipe E	kg	1.03E+04	0.00E+00	0.00E+00	2.06E+03	2.06E+03	4.12E+03	0.00E+00	2.06E+03	2.06E+04
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	kg	0.00E+00	3.18E+03	6.36E+02	0.00E+00	8.37E+03	2.71E+03	1.59E+03	0.00E+00	1.65E+04
Polyethylene, HDPE, granulate, at plant/RER U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
St13 I - Material	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper I - Material	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper product manufacturing, average metal working/RER U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminium, production mix, at plant/RER U - Material	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminium product manufacturing, average metal working/RER U - Processing	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chemical										
Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sodium hypochlorite, 15% in H2O, at plant/RER U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E+07	0.00E+00	1.11E+07
Lime, hydrated, packed, at plant/CH U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Quicklime, milled, packed, at plant/CH U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sulphuric acid, liquid, at plant/RER U	kg	0.00E+00	0.00E+00	5.94E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.94E+06
Aluminium sulphate, powder, at plant/RER U	kg	0.00E+00	2.21E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.21E+07
Iron (III) chloride, 40% in H2O, at plant/CH U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric acid, 30% in H2O, at plant/RER U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ammonium sulphate, as N, at regional storehouse/RER U	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Energy										
Electricity, high voltage, at grid/US U	kWh	1.64E+07	3.14E+05	3.14E+05	2.01E+06	1.06E+06	6.40E+05	3.14E+05	8.14E+05	2.19E+07
Natural gas, at consumer/RNA U	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Environmental Impacts of Unit Quantity Inventories

Impact category	Quantity	Unit	Global warming	Water intake	Acidification	HH cancer	HH noncancer	HH criteria air pollutants	Eutrophication	Ecotoxicity	Smog	Natural resource depletion	Indoor air quality	Habitat alteration
Unit			g CO2 eq	liters	H+ moles eq	g C7H7 eq	g C7H7 eq	microDALYs	g N eq	g 2,4-D eq	g NOx eq	MJ surplus	TVOC eq	T&E count
Equipment														
Pumps and compressors	1	USD	8.05E+02	0.00E+00	1.89E+02	1.33E+01	2.89E+03	8.86E-02	1.80E-01	5.42E+00	3.37E+00	1.15E+00	0.00E+00	0.00E+00
Blowers and fans	1	USD	8.93E+02	0.00E+00	2.07E+02	1.29E+01	2.67E+03	9.66E-02	2.35E-01	5.22E+00	3.55E+00	1.19E+00	0.00E+00	0.00E+00
Measuring and dispensing pumps	1	USD	8.83E+02	0.00E+00	2.16E+02	1.54E+01	3.35E+03	9.62E-02	2.17E-01	5.50E+00	3.74E+00	1.31E+00	0.00E+00	0.00E+00
Conveyors and conveying equipment	1	USD	8.88E+02	0.00E+00	1.97E+02	1.31E+01	2.50E+03	9.38E-02	1.82E-01	5.41E+00	3.44E+00	1.15E+00	0.00E+00	0.00E+00
Industrial trucks and tractors	1	USD	1.16E+03	0.00E+00	2.63E+02	1.80E+01	3.48E+03	1.23E-01	2.36E-01	8.34E+00	4.91E+00	1.50E+00	0.00E+00	0.00E+00
Pipe, valves, and pipe fittings	1	USD	1.06E+03	0.00E+00	2.55E+02	1.73E+01	6.58E+03	1.26E-01	2.19E-01	6.25E+00	4.06E+00	1.35E+00	0.00E+00	0.00E+00
Plumbing fixture fittings and trim	1	USD	9.18E+02	0.00E+00	2.66E+02	1.74E+01	9.95E+03	1.26E-01	2.20E-01	6.48E+00	4.12E+00	1.45E+00	0.00E+00	0.00E+00
Turbines and turbine generator sets	1	USD	8.78E+02	0.00E+00	1.95E+02	1.30E+01	3.01E+03	9.44E-02	1.74E-01	6.11E+00	3.50E+00	1.13E+00	0.00E+00	0.00E+00
Motors and generators	1	USD	1.08E+03	0.00E+00	2.68E+02	1.72E+01	4.25E+03	1.26E-01	2.23E-01	1.21E+01	4.60E+00	1.46E+00	0.00E+00	0.00E+00
Water supply and sewerage systems	1	USD	2.00E+03	0.00E+00	2.87E+02	1.72E+01	1.22E+03	1.09E-01	3.15E-01	2.79E+00	4.76E+00	3.22E+00	0.00E+00	0.00E+00
Material														
Reinforcing steel, at plant/RER U	1	kg	1.40E+03	2.58E+01	2.64E+02	1.44E+01	4.21E+04	5.09E-01	2.28E-01	1.08E+02	3.73E+00	1.09E+00	0.00E+00	2.49E-14
Concrete, normal, at plant/CH U	1	m3	2.59E+05	3.83E+03	2.56E+04	5.19E+02	1.07E+06	8.73E+00	3.04E+01	1.14E+03	5.58E+02	9.63E+01	0.00E+00	8.06E-13
Concrete (reinforced) I	1	kg	1.07E+02	1.92E+00	4.01E+01	6.89E+00	9.26E+03	6.68E-03	2.85E-02	4.28E-01	7.94E-01	1.87E-01	0.00E+00	0.00E+00
Brick, at plant/RER U	1	kg	2.12E+02	1.21E+00	3.15E+01	6.73E-02	7.62E+01	8.10E-03	3.43E-02	2.42E-01	5.88E-01	3.28E-01	0.00E+00	1.40E-16
Wood board ETH U	1	kg	-2.43E+03	1.16E+01	1.78E+02	1.74E+00	2.62E+03	3.06E-02	1.43E-01	2.32E+00	2.34E+00	6.06E-01	0.00E+00	0.00E+00
Sand ETH U	1	kg	9.73E+00	9.31E-02	2.72E+00	1.63E-03	7.32E+00	3.55E-04	2.55E-03	2.21E-02	5.55E-02	1.60E-02	0.00E+00	0.00E+00
Hard coal mix, at regional storage/UCTE U	1	kg	2.68E+02	3.46E+00	8.22E+01	1.40E-01	2.63E+03	1.38E-01	7.15E-02	4.62E-01	1.35E+00	4.72E-01	0.00E+00	3.73E-14
Gravel ETH U	1	kg	1.02E+01	1.12E-01	2.87E+00	2.02E-03	8.41E+00	3.92E-04	2.66E-03	2.53E-02	5.64E-02	1.64E-02	0.00E+00	0.00E+00
HDPE pipes E	1	kg	2.44E+03	4.65E+01	5.01E+02	7.15E-01	8.68E+01	1.63E-01	2.15E-01	1.12E+00	1.04E+01	0.00E+00	0.00E+00	0.00E+00
PVC pipe E	1	kg	3.18E+03	7.43E+01	7.42E+02	5.32E+02	6.77E+05	2.61E-01	9.62E-01	3.90E+01	9.79E+00	0.00E+00	0.00E+00	0.00E+00
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	1	kg	8.61E+03	6.01E+02	1.62E+03	4.23E+00	3.04E+03	6.23E-01	8.22E+00	1.02E+01	1.76E+01	1.64E+01	0.00E+00	1.87E-14
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	1	kg	4.67E+03	1.57E+02	8.88E+02	6.36E+01	3.34E+04	3.27E-01	4.68E+00	3.53E+01	1.11E+01	8.84E+00	0.00E+00	1.34E-14
Polyethylene, HDPE, granulate, at plant/RER U	1	kg	1.90E+03	3.40E+02	9.69E-01	1.74E+02	1.10E-01	1.61E-01	6.43E-01	4.11E+00	1.01E+01	0.00E+00	7.86E-16	3.22E+01
St13 I - Material	1	kg	1.00E+03	5.27E+02	1.72E+02	2.31E+05	9.32E-02	2.70E-01	9.57E+00	8.87E+00	8.46E-01	0.00E+00	0.00E+00	1.18E+00
Copper I - Material	1	kg	7.51E+03	3.52E+04	1.29E-02	1.42E+01	9.42E+00	1.09E+00	6.28E-01	3.11E+01	1.25E+01	0.00E+00	0.00E+00	1.26E-01
Copper product manufacturing, average metal working/RER U	1	kg	1.80E+03	1.66E+03	1.45E+02	3.07E+05	8.02E-01	1.21E+00	5.28E+01	8.56E+00	2.27E+00	0.00E+00	7.42E-13	6.18E+01
Aluminium, production mix, at plant/RER U - Material	1	kg	7.77E+03	1.88E+03	3.29E+01	2.22E+04	1.43E+00	1.68E+00	3.13E+01	1.66E+01	7.99E+00	0.00E+00	8.57E-14	2.03E+02
Aluminium product manufacturing, average metal working/RER U - Processing	1	kg	3.17E+03	6.47E+02	1.08E+01	9.71E+03	4.07E-01	1.18E+00	1.48E+01	6.44E+00	3.57E+00	0.00E+00	2.47E-14	9.11E+01
Chemical														
Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	1	kg	1.01E+03	1.13E+02	2.36E+02	1.21E+00	1.50E+04	9.72E-02	2.93E-01	7.71E+01	2.16E+00	8.96E-01	0.00E+00	7.46E-15
Sodium hypochlorite, 15% in H2O, at plant/RER U	1	kg	7.63E+02	6.50E+01	1.74E+02	8.30E-01	8.72E+03	7.19E-02	2.15E-01	4.37E+01	1.90E+00	8.71E-01	0.00E+00	4.77E-15
Lime, hydrated, packed, at plant/CH U	1	kg	7.57E+02	2.30E+00	3.77E+01	3.54E-01	7.76E+02	2.48E-02	4.24E-02	3.42E-01	6.33E-01	5.19E-01	0.00E+00	9.25E-17
Quicklime, milled, packed, at plant/CH U	1	kg	9.82E+02	2.04E+00	4.85E+01	3.89E-01	9.37E+02	3.21E-02	5.32E-02	4.35E-01	8.14E-01	6.73E-01	0.00E+00	1.14E-16
Sulphuric acid, liquid, at plant/RER U	1	kg	8.60E+01	5.07E+01	6.75E+02	1.04E-01	1.64E+02	1.82E-01	6.29E-02	3.67E-01	8.42E-01	1.54E-01	0.00E+00	1.46E-16
Aluminium sulphate, powder, at plant/RER U	1	kg	4.58E+02	3.89E+01	4.44E+02	3.25E+00	1.40E+03	2.02E-01	1.29E-01	3.68E+00	1.65E+00	5.59E-01	0.00E+00	6.50E-15
Iron (III) chloride, 40% in H2O, at plant/CH U	1	kg	6.17E+02	6.38E+01	1.50E+02	1.87E+00	1.29E+04	6.08E-02	1.90E-01	6.69E+01	1.46E+00	5.64E-01	0.00E+00	4.49E-15
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	1	kg	1.17E+03	2.75E+02	3.15E+00	1.50E+04	1.12E-01	3.11E-01	7.66E+01	2.53E+00	1.27E+00	0.00E+00	8.09E-15	1.18E+02
Hydrochloric acid, 30% in H2O, at plant/RER U	1	kg	7.35E+02	1.82E+02	1.77E+00	7.83E+03	7.20E-02	2.87E-01	3.91E+01	1.61E+00	8.79E-01	0.00E+00	5.04E-15	7.25E+01
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	1	kg	1.21E+03	1.67E+03	3.14E+01	7.13E+03	6.57E-01	1.06E+02	6.46E+00	4.16E+00	1.79E+00	0.00E+00	2.93E-14	1.56E+02
Ammonium sulphate, as N, at regional storehouse/RER U	1	kg	2.37E+03	3.45E+02	1.22E+00	3.02E+03	1.51E-01	3.45E-01	4.64E+00	3.84E+00	5.56E+00	0.00E+00	3.50E-15	7.71E+00
Energy														
Electricity, high voltage, at grid/US U	1	kWh	7.48E+02	2.67E+01	2.64E+02	1.53E+00	2.62E+03	8.97E-02	9.43E-02	1.93E+00	1.74E+00	5.04E-01	0.00E+00	1.72E-14
Natural gas, at consumer/RNA U	1	MJ	1.32E+01	3.44E-02	2.83E+01	3.34E-01	3.89E+02	7.76E-03	3.66E-03	8.95E-02	2.48E-02	1.81E-01	0.00E+00	2.21E-17

Water Research Foundation

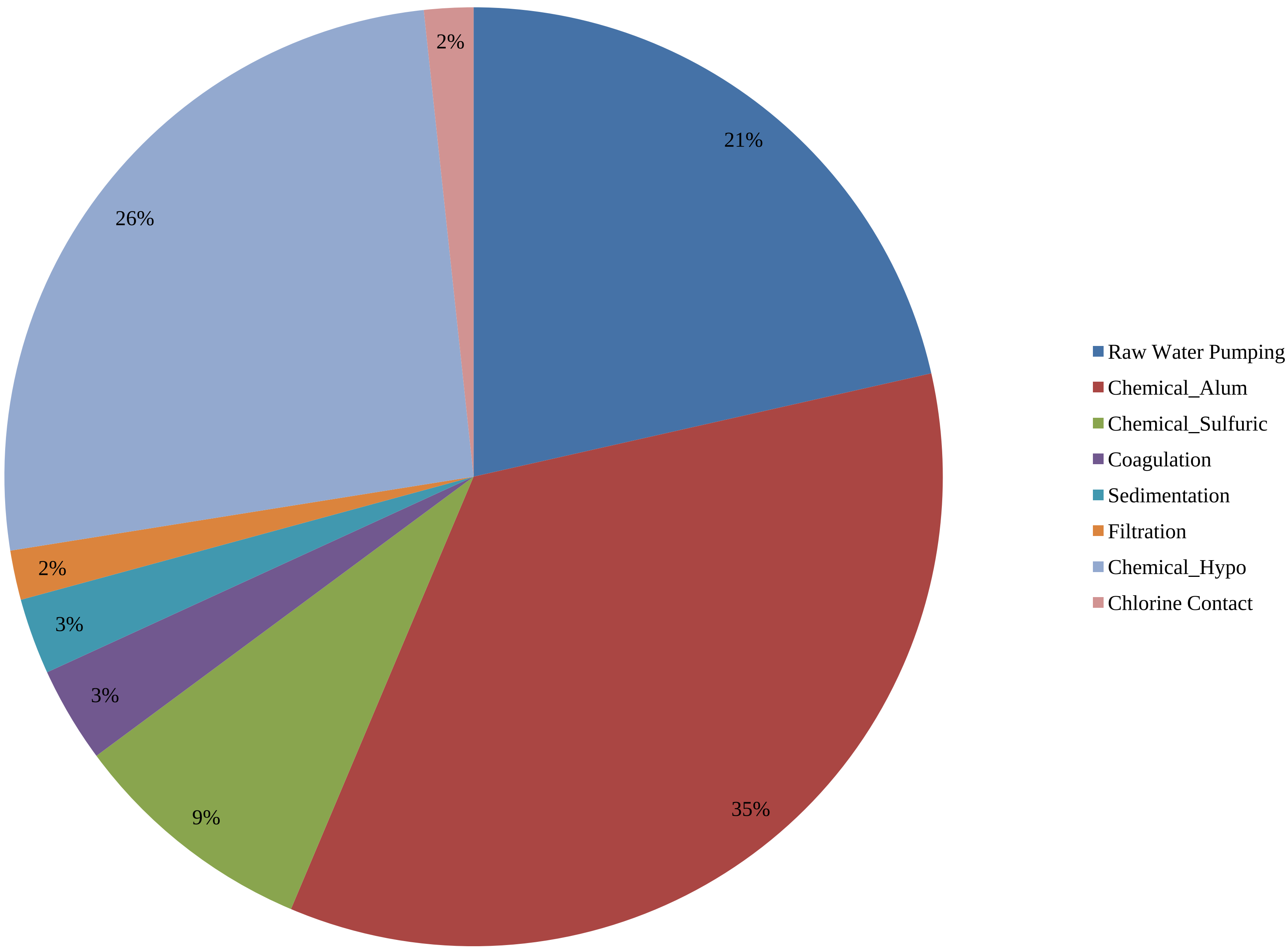
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Life Cyccle Environmental Impacts for Water Treatment Facilities

Unit Process (Selected on Main Page) Entire Facility

Impact category	Global warming	Water intake	Acidification	HH cancer	HH noncancer	HH criteria air pollutants	Eutrophication	Ecotoxicity	Smog	Natural resource depletion	Indoor air quality	Habitat alteration	Ozone depletion
Unit	**g CO2 eq**	**liters**	**H+ moles eq**	**g C7H7 eq**	**g C7H7 eq**	**microDALYs**	**g N eq**	**g 2,4-D eq**	**g NOx eq**	**MJ surplus**	**TVOC eq**	**T&E count**	**g CFC-11 eq**
Total	**5.83E+10**	**2.80E+09**	**2.40E+10**	**1.83E+08**	**3.08E+11**	**9.33E+06**	**1.05E+07**	**7.53E+08**	**1.52E+08**	**4.32E+07**	**0.00E+00**	**6.55E-07**	**0.00E+00**
Equipment													
Pumps and compressors	4.09E+08	0.00E+00	9.60E+07	6.76E+06	1.47E+09	4.50E+04	9.17E+04	2.76E+06	1.71E+06	5.82E+05	0.00E+00	0.00E+00	0.00E+00
Blowers and fans	1.66E+07	0.00E+00	3.84E+06	2.40E+05	4.97E+07	1.80E+03	4.37E+03	9.70E+04	6.60E+04	2.21E+04	0.00E+00	0.00E+00	0.00E+00
Measuring and dispensing pumps	1.32E+07	0.00E+00	3.24E+06	2.31E+05	5.02E+07	1.44E+03	3.26E+03	8.25E+04	5.60E+04	1.97E+04	0.00E+00	0.00E+00	0.00E+00
Conveyors and conveying equipment	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Industrial trucks and tractors	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pipe, valves, and pipe fittings	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plumbing fixture fittings and trim	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turbines and turbine generator sets	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Motors and generators	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water supply and sewerage systems	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Material													
Reinforcing steel, at plant/RER U	5.86E+08	1.08E+07	1.11E+08	6.03E+06	1.76E+10	2.13E+05	9.54E+04	4.52E+07	1.56E+06	4.56E+05	0.00E+00	1.04E-08	0.00E+00
Concrete, normal, at plant/CH U	2.14E+10	3.16E+08	2.11E+09	4.28E+07	8.85E+10	7.20E+05	2.50E+06	9.42E+07	4.60E+07	7.93E+06	0.00E+00	6.64E-08	0.00E+00
Concrete (reinforced) I	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Brick, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wood board ETH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sand ETH U	1.65E+06	1.58E+04	4.61E+05	2.76E+02	1.24E+06	6.04E+01	4.33E+02	3.75E+03	9.43E+03	2.73E+03	0.00E+00	0.00E+00	0.00E+00
Hard coal mix, at regional storage/UCTE U	3.95E+07	5.12E+05	1.21E+07	2.07E+04	3.89E+08	2.04E+04	1.06E+04	6.83E+04	1.99E+05	6.97E+04	0.00E+00	5.51E-09	0.00E+00
Gravel ETH U	7.51E+05	8.28E+03	2.12E+05	1.49E+02	6.21E+05	2.89E+01	1.97E+02	1.87E+03	4.17E+03	1.21E+03	0.00E+00	0.00E+00	0.00E+00
HDPE pipes E	3.07E+08	5.86E+06	6.30E+07	9.00E+04	1.09E+07	2.05E+04	2.71E+04	1.41E+05	1.31E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PVC pipe E	6.54E+07	1.53E+06	1.53E+07	1.10E+07	1.39E+10	5.38E+03	1.98E+04	8.03E+05	2.02E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	7.70E+07	2.59E+06	1.46E+07	1.05E+06	5.50E+08	5.40E+03	7.71E+04	5.82E+05	1.83E+05	1.46E+05	0.00E+00	2.21E-10	0.00E+00
Polyethylene, HDPE, granulate, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
St13 I - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper I - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper product manufacturing, average metal working/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminium, production mix, at plant/RER U - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminium product manufacturing, average metal working/RER U - Processing	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chemical													
Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sodium hypochlorite, 15% in H2O, at plant/RER U	8.44E+09	7.19E+08	1.92E+09	9.17E+06	9.64E+10	7.95E+05	2.38E+06	4.83E+08	2.11E+07	9.63E+06	0.00E+00	5.28E-08	0.00E+00
Lime, hydrated, packed, at plant/CH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Quicklime, milled, packed, at plant/CH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sulphuric acid, liquid, at plant/RER U	5.11E+08	3.01E+08	4.01E+09	6.20E+05	9.77E+08	1.08E+06	3.74E+05	2.18E+06	5.01E+06	9.16E+05	0.00E+00	8.67E-10	0.00E+00
Aluminium sulphate, powder, at plant/RER U	1.01E+10	8.59E+08	9.83E+09	7.19E+07	3.11E+10	4.46E+06	2.85E+06	8.14E+07	3.66E+07	1.24E+07	0.00E+00	1.44E-07	0.00E+00
Iron (III) chloride, 40% in H2O, at plant/CH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric acid, 30% in H2O, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ammonium sulphate, as N, at regional storehouse/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Energy													
Electricity, high voltage, at grid/US U	1.64E+10	5.85E+08	5.77E+09	3.34E+07	5.73E+10	1.96E+06	2.06E+06	4.22E+07	3.81E+07	1.10E+07	0.00E+00	3.75E-07	0.00E+00
Natural gas, at consumer/RNA U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Global Warming Breakdown by Process



Water Research Foundation

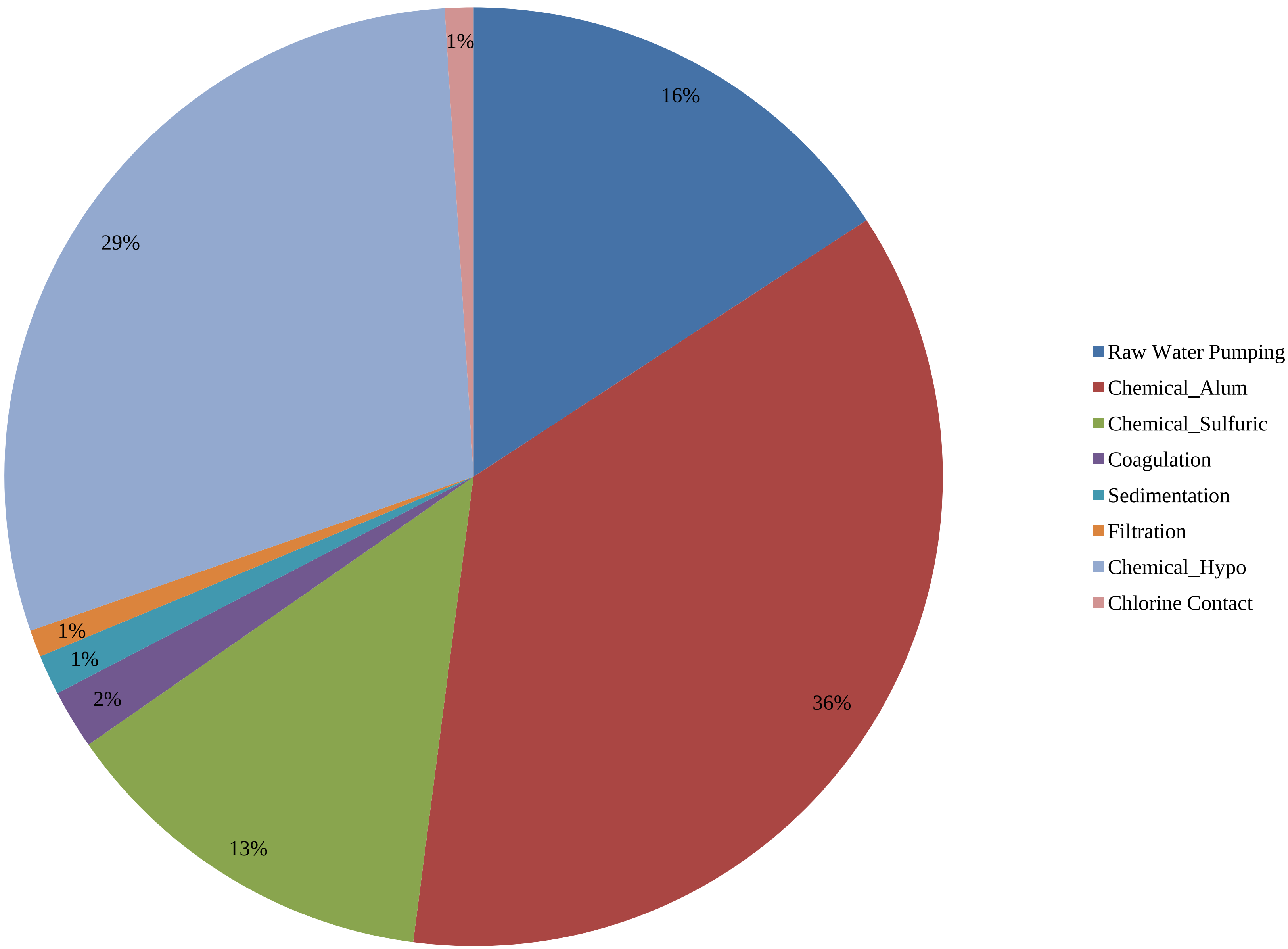
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Life Cyccle Environmental Impacts for Water Treatment Facilities

Global Warming

	Raw Water Pumping	Chemical_Alum	Chemical_Sulfuric	Coagulation	Sedimentation	Filtration	Chemical_Hypo	Chlorine Contact	Entire Facility
Impact category	**Global warming**	**Global warming**	**Global warming**	**Global warming**	**Global warming**	**Global warming**	**Global warming**	**Global warming**	**Global warming**
Unit	**g CO2 eq**	**g CO2 eq**	**g CO2 eq**	**g CO2 eq**	**g CO2 eq**	**g CO2 eq**	**g CO2 eq**	**g CO2 eq**	**g CO2 eq**
Total	**1.25E+10**	**2.03E+10**	**4.96E+09**	**1.92E+09**	**1.53E+09**	**9.92E+08**	**1.51E+10**	**9.89E+08**	**5.83E+10**
Percentage	**21%**	**35%**	**9%**	**3%**	**3%**	**2%**	**26%**	**2%**	**100%**
Equipment									
Pumps and compressors	1.59E+07	0.00E+00	0.00E+00	2.04E+08	1.53E+08	9.97E+06	0.00E+00	2.57E+07	4.09E+08
Blowers and fans	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.66E+07	0.00E+00	0.00E+00	1.66E+07
Measuring and dispensing pumps	0.00E+00	4.42E+06	4.42E+06	0.00E+00	0.00E+00	0.00E+00	4.42E+06	0.00E+00	1.32E+07
Conveyors and conveying equipment	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Industrial trucks and tractors	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pipe, valves, and pipe fittings	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plumbing fixture fittings and trim	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turbines and turbine generator sets	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Motors and generators	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water supply and sewerage systems	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Material									
Reinforcing steel, at plant/RER U	8.59E+07	4.50E+03	1.83E+03	8.22E+07	2.20E+08	4.53E+07	2.83E+03	1.53E+08	5.86E+08
Concrete, normal, at plant/CH U	1.12E+08	9.97E+09	4.20E+09	1.24E+08	3.18E+08	6.66E+07	6.37E+09	1.95E+08	2.14E+10
Concrete (reinforced) I	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Brick, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wood board ETH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sand ETH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.65E+06	0.00E+00	0.00E+00	1.65E+06
Hard coal mix, at regional storage/UCTE U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.95E+07	0.00E+00	0.00E+00	3.95E+07
Gravel ETH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.51E+05	0.00E+00	0.00E+00	7.51E+05
HDPE pipes E	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.07E+08	0.00E+00	0.00E+00	3.07E+08
PVC pipe E	3.27E+07	0.00E+00	0.00E+00	6.54E+06	6.54E+06	1.31E+07	0.00E+00	6.54E+06	6.54E+07
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	0.00E+00	1.49E+07	2.97E+06	0.00E+00	3.91E+07	1.27E+07	7.43E+06	0.00E+00	7.70E+07
Polyethylene, HDPE, granulate, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
St13 I - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper I - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper product manufacturing, average metal working/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminium, production mix, at plant/RER U - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminium product manufacturing, average metal working/RER U - Processing	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chemical									
Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sodium hypochlorite, 15% in H2O, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.44E+09	0.00E+00	8.44E+09
Lime, hydrated, packed, at plant/CH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Quicklime, milled, packed, at plant/CH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sulphuric acid, liquid, at plant/RER U	0.00E+00	0.00E+00	5.11E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.11E+08
Aluminium sulphate, powder, at plant/RER U	0.00E+00	1.01E+10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E+10
Iron (III) chloride, 40% in H2O, at plant/CH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric acid, 30% in H2O, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ammonium sulphate, as N, at regional storehouse/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Energy									
Electricity, high voltage, at grid/US U	1.23E+10	2.35E+08	2.35E+08	1.50E+09	7.91E+08	4.79E+08	2.35E+08	6.09E+08	1.64E+10
Natural gas, at consumer/RNA U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Water Intake Breakdown by Process



Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Life Cyccle Environmental Impacts for Water Treatment Facilities

Water Intake

	Raw Water Pumping	Chemical_Alum	Chemical_Sulfuric	Coagulation	Sedimentation	Filtration	Chemical_Hypo	Chlorine Contact	Entire Facility
Impact category	**Water intake**	**Water intake**	**Water intake**	**Water intake**	**Water intake**	**Water intake**	**Water intake**	**Water intake**	**Water intake**
Unit	**liter**	**liter**	**liter**	**liter**	**liter**	**liter**	**liter**	**liter**	**liter**
Total	**4.43E+08**	**1.02E+09**	**3.72E+08**	**5.72E+07**	**3.85E+07**	**2.61E+07**	**8.22E+08**	**2.76E+07**	**2.80E+09**
Percentage	**16%**	**36%**	**13%**	**2%**	**1%**	**1%**	**29%**	**1%**	**100%**
Equipment									
Pumps and compressors	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Blowers and fans	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Measuring and dispensing pumps	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Conveyors and conveying equipment	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Industrial trucks and tractors	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pipe, valves, and pipe fittings	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plumbing fixture fittings and trim	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turbines and turbine generator sets	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Motors and generators	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water supply and sewerage systems	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Material									
Reinforcing steel, at plant/RER U	1.58E+06	8.30E+01	3.37E+01	1.52E+06	4.05E+06	8.35E+05	5.22E+01	2.81E+06	1.08E+07
Concrete, normal, at plant/CH U	1.66E+06	1.48E+08	6.22E+07	1.84E+06	4.70E+06	9.85E+05	9.42E+07	2.89E+06	3.16E+08
Concrete (reinforced) I	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Brick, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wood board ETH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sand ETH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.58E+04	0.00E+00	0.00E+00	1.58E+04
Hard coal mix, at regional storage/UCTE U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.12E+05	0.00E+00	0.00E+00	5.12E+05
Gravel ETH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.28E+03	0.00E+00	0.00E+00	8.28E+03
HDPE pipes E	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.86E+06	0.00E+00	0.00E+00	5.86E+06
PVC pipe E	7.65E+05	0.00E+00	0.00E+00	1.53E+05	1.53E+05	3.06E+05	0.00E+00	1.53E+05	1.53E+06
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	0.00E+00	5.00E+05	1.00E+05	0.00E+00	1.32E+06	4.26E+05	2.50E+05	0.00E+00	2.59E+06
Polyethylene, HDPE, granulate, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
St13 I - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper I - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper product manufacturing, average metal working/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminium, production mix, at plant/RER U - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminium product manufacturing, average metal working/RER U - Processing	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chemical									
Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sodium hypochlorite, 15% in H2O, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.19E+08	0.00E+00	7.19E+08
Lime, hydrated, packed, at plant/CH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Quicklime, milled, packed, at plant/CH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sulphuric acid, liquid, at plant/RER U	0.00E+00	0.00E+00	3.01E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.01E+08
Aluminium sulphate, powder, at plant/RER U	0.00E+00	8.59E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.59E+08
Iron (III) chloride, 40% in H2O, at plant/CH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hydrochloric acid, 30% in H2O, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ammonium sulphate, as N, at regional storehouse/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Energy									
Electricity, high voltage, at grid/US U	4.39E+08	8.39E+06	8.39E+06	5.37E+07	2.83E+07	1.71E+07	8.39E+06	2.18E+07	5.85E+08
Natural gas, at consumer/RNA U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

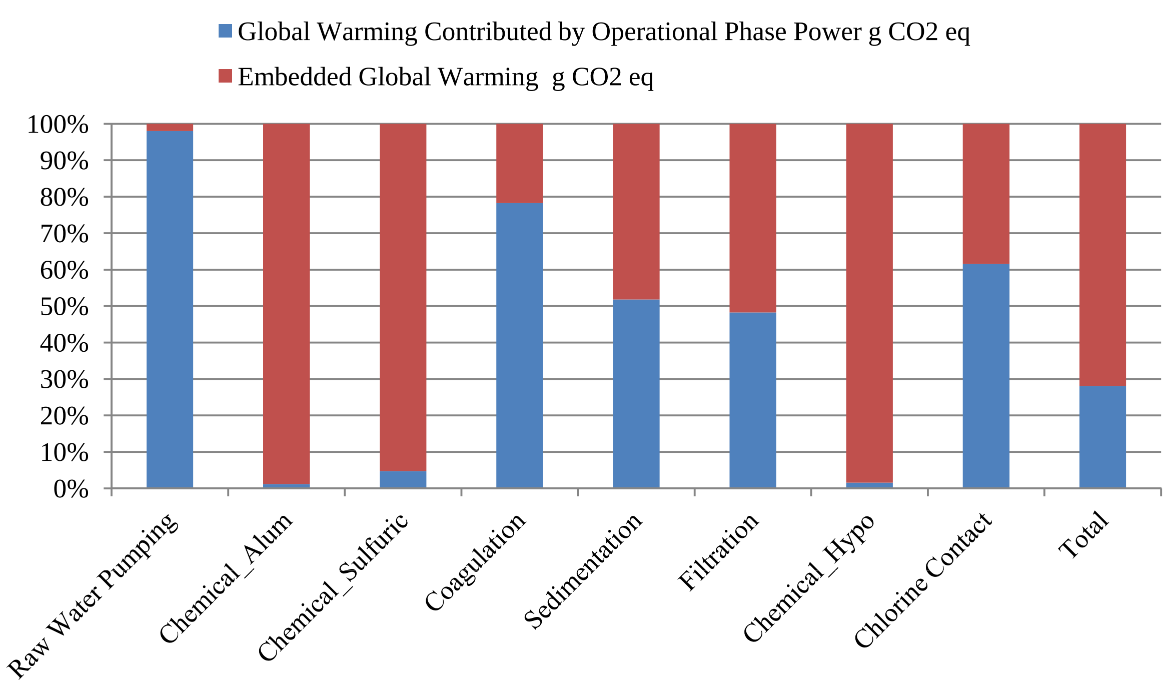
Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Life Cyccle Environmental Impacts for Water Treatment Facilities

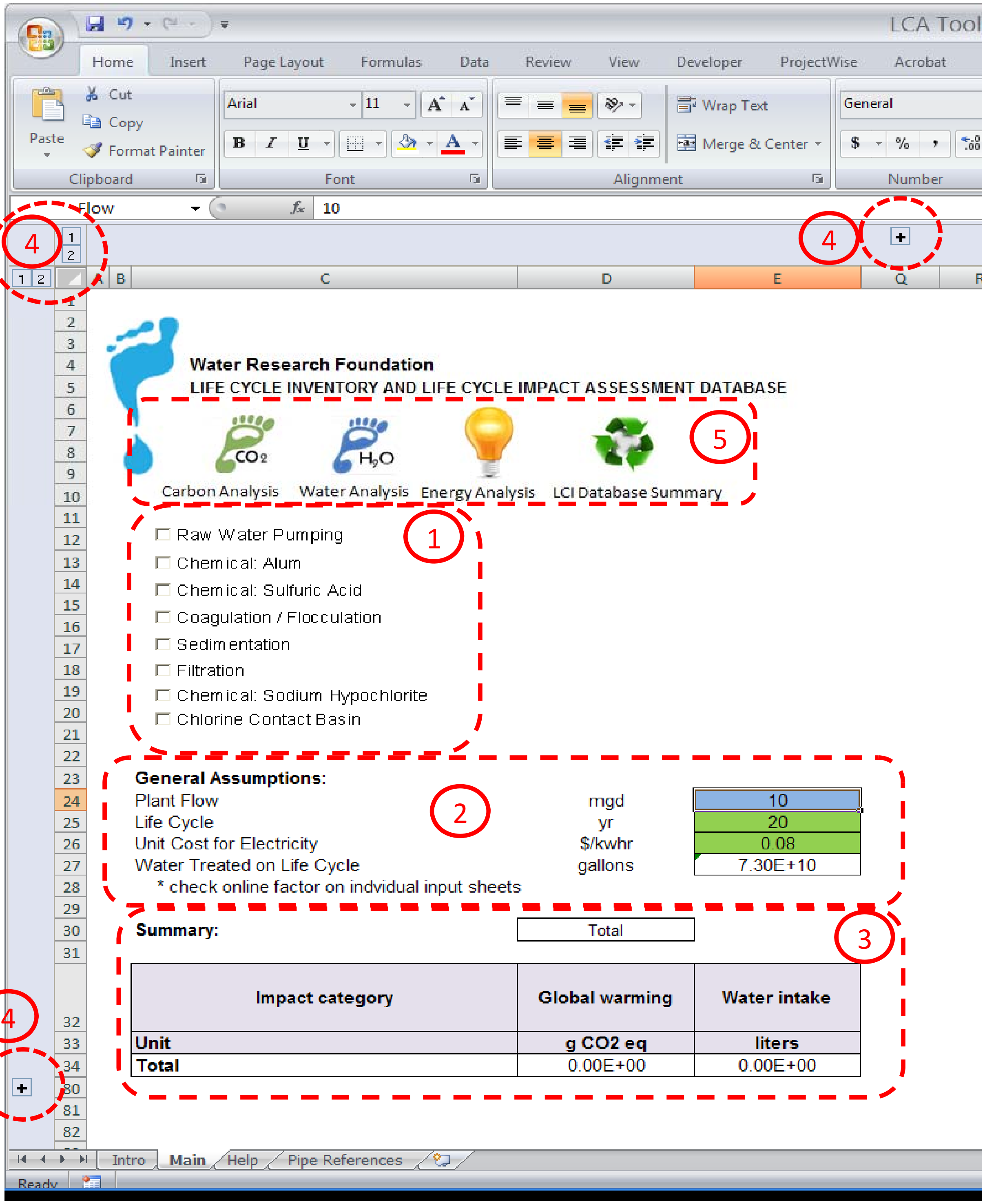
Operational Phase Energy Consumption by Process

Process	Operational Phase Electricity, high voltage, at grid/US U	Global Warming Contributed by Operational Phase Power	Embedded Global Warming	Total Global Warming
	kWh	g CO2 eq	g CO2 eq	g CO2 eq
Raw Water Pumping	1.64E+07	1.23E+10	2.46E+08	1.25E+10
Chemical_Alum	3.14E+05	2.35E+08	2.01E+10	2.03E+10
Chemical_Sulfuric	3.14E+05	2.35E+08	4.72E+09	4.96E+09
Coagulation	2.01E+06	1.50E+09	4.18E+08	1.92E+09
Sedimentation	1.06E+06	7.91E+08	7.36E+08	1.53E+09
Filtration	6.40E+05	4.79E+08	5.13E+08	9.92E+08
Chemical_Hypo	3.14E+05	2.35E+08	1.48E+10	1.51E+10
Chlorine Contact	8.14E+05	6.09E+08	3.80E+08	9.89E+08
Total	2.19E+07	1.64E+10	4.19E+10	5.83E+10



LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE QUICK GUIDE

Click on the image or click on "Main" Workbook to start.



1 On Main Workbook, check the boxes to select water treatment moduels and assemble your water treatment plant. New workbook will be generated when the corresponding checkboxes are selected.

- [ ] Raw Water Pumping
- [ ] Chemical: Alum
- [ ] Chemical: Sulfuric Acid
- [ ] Coagulation / Flocculation
- [x] Sedimentation
- [x] Filtration
- [ ] Chemical: Sodium Hypochlorite
- [ ] Chlorine Contact Basin

2 Input plant capacity. Adjust life cycle length and unit cost for electricity.

22			
23	**General Assumptions:**		
24	Plant Flow	mgd	10
25	Life Cycle	yr	20
26	Unit Cost for Electricity	$/kwhr	0.08
27	Water Treated on Life Cycle	gallons	7.30E+10
28	* check online factor on indvidual input sheets		

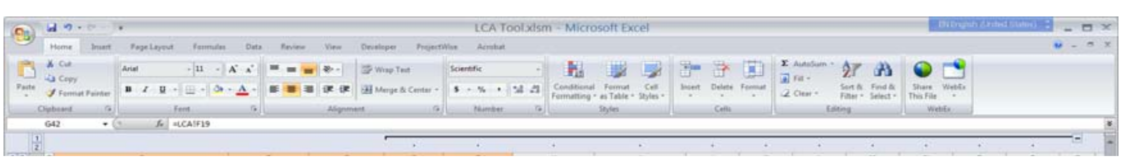
3 Review result summary in this area. Use drop down menu to view environmental impact results for individual process or entire treatment facility.

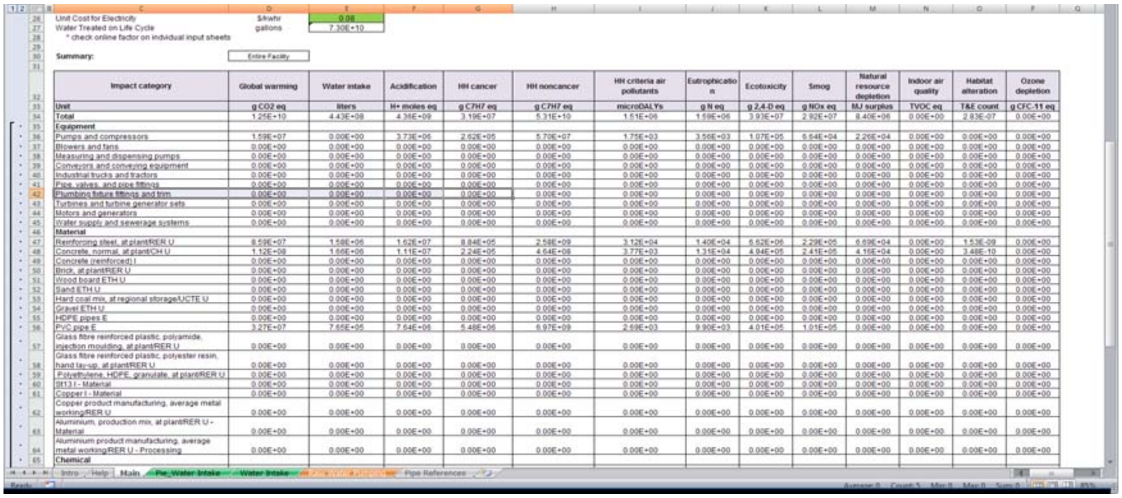
Summary: Entire Facility

Chemical_Alum
Chemical_Sulfuric
Coag-Floc
Sedimentation
Filtration
Chemical_Hypochlorite
Chlorine Contact
Entire Facility

Impact category		Water intake
Unit		liters
Total	1.25E+10	4.43E+08

4 Click on the expand and collapse hidden details to view breakdown results by inventory items (e.g., material, energy) and impact data for additional environmental categories.





Unit Cost for Electricity $/kwhr 0.08
Water Treated on Life Cycle gallons 7.30E+10
* check online factor on individual input sheets

Summary: Entire Facility

Impact category	Global warming	Water intake	Acidification	HH cancer	HH noncancer	HH criteria air pollutants	Eutrophication	Ecotoxicity	Smog	Natural resource depletion	Indoor air quality	Habitat alteration	Ozone depletion
Unit	g CO2 eq	liters	H+ moles eq	g C7H7 eq	g C7H7 eq	microDALYs	g N eq	g 2,4-D eq	g NOx eq	MJ surplus	TVOC eq	T&E count	g CFC-11 eq
Total	1.25E+10	4.43E+08	4.36E+09	3.19E+07	5.31E+10	1.51E+06	1.59E+06	3.93E+07	2.92E+07	8.40E+06	0.00E+00	2.83E-07	0.00E+00
Equipment													
Pumps and compressors	1.59E+07	0.00E+00	3.73E+06	2.62E+05	5.70E+07	1.75E+03	3.56E+03	1.07E+05	6.64E+04	2.26E+04	0.00E+00	0.00E+00	0.00E+00
Blowers and fans	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Measuring and dispensing pumps	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Conveyors and conveying equipment	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Industrial trucks and tractors	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pipe, valves, and pipe fittings	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plumbing fixture fittings and trim	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turbines and turbine generator sets	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Motors and generators	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water supply and sewerage systems	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Material													
Reinforcing steel, at plant/RER U	8.59E+07	1.58E+06	1.62E+07	8.84E+05	2.58E+09	3.12E+04	1.40E+04	6.62E+06	2.29E+05	6.69E+04	0.00E+00	1.53E-09	0.00E+00
Concrete, normal, at plant/CH U	1.12E+08	1.66E+06	1.11E+07	2.24E+05	4.64E+08	3.77E+03	1.31E+04	4.94E+05	2.41E+05	4.16E+04	0.00E+00	3.48E-10	0.00E+00
Concrete (reinforced) I	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Brick, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wood board ETH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sand ETH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hard coal mix, at regional storage/UCTE U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Gravel ETH U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
HDPE pipes E	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PVC pipe E	3.27E+07	7.65E+05	7.64E+06	5.48E+06	6.97E+09	2.69E+03	9.90E+03	4.01E+05	1.01E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Polyethylene, HDPE, granulate, at plant/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
St13 I - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper I - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Copper product manufacturing, average metal working/RER U	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminium, production mix, at plant/RER U - Material	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminium product manufacturing, average metal working/RER U - Processing	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chemical													

Intro Help Main Pie_Water Intake Water Intake Pipe References

5 Use the buttons to view results of additional analysis


Carbon Analysis

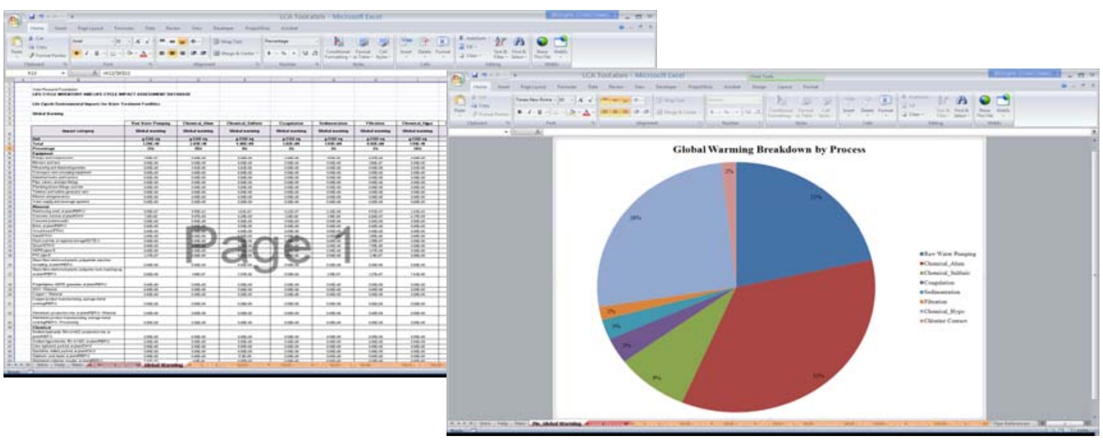

Water Analysis


Energy Analysis


LCI Database Summary

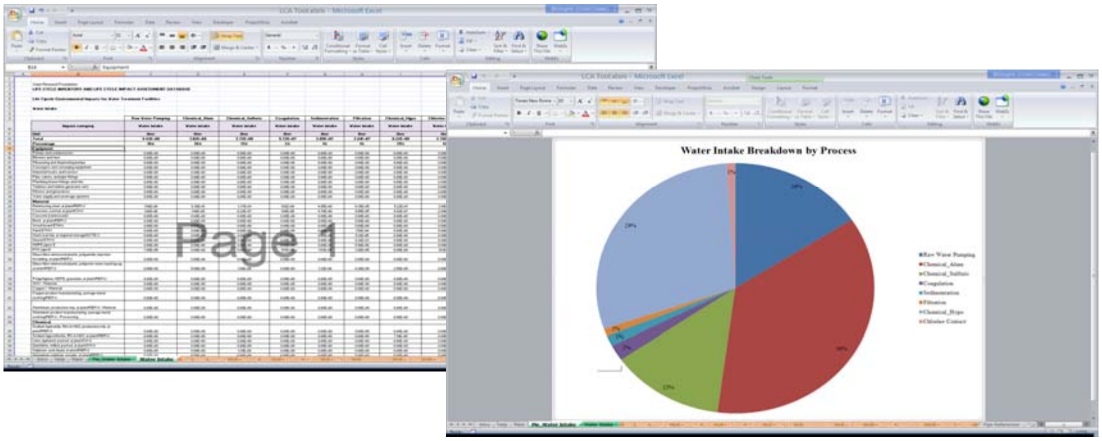

Carbon Analysis

Carbon Emission Analysis Detailed Breakdown Results by Inventory Item (e.g., material, energy) and by process area (e.g., coagulation, sedimentation).



Water Analysis

Water Intake Analysis Detailed Breakdown Results by Inventory Item (e.g., material, energy) and by process area (e.g., coagulation, sedimentation).



Energy Analysis

Energy analysis for energy consumed during the operation of the water treatment facility versus the embedded energy used for producing the chemicals, equipment, material, and energy.

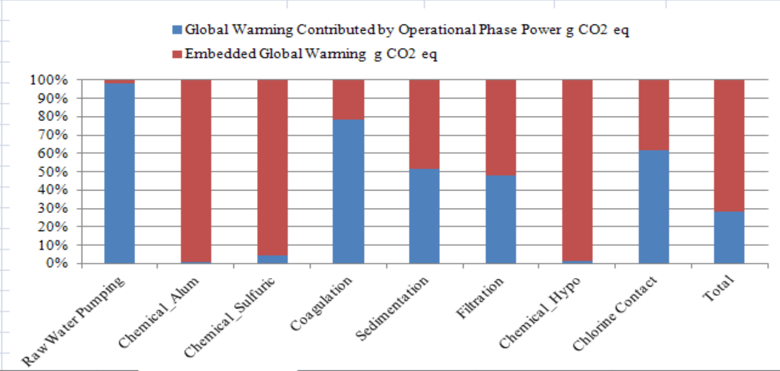
Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Life Cyccle Environmental Impacts for Water Treatment Facilities

Operational Phase Energy Consumption by Process

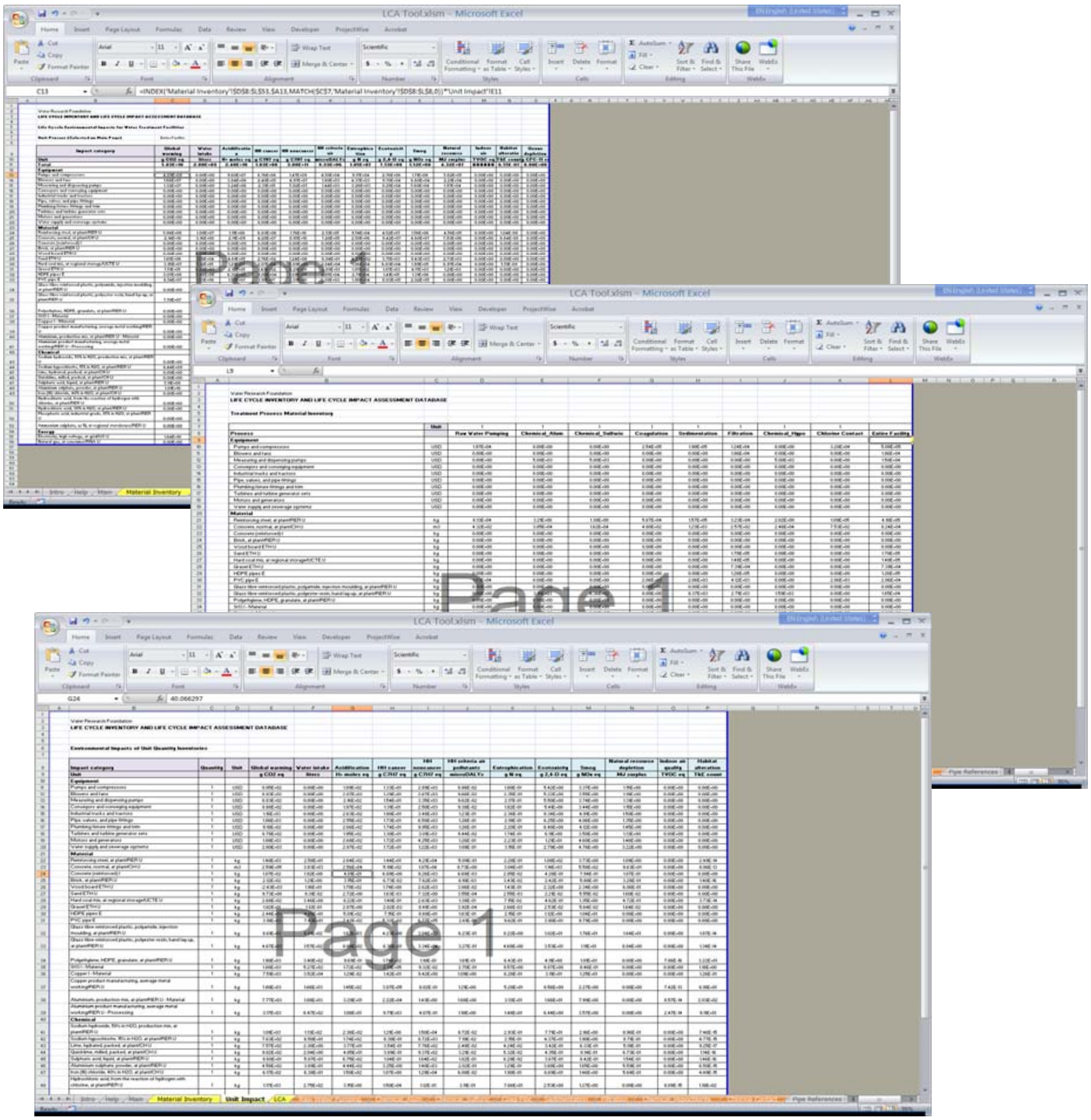
Process	Operational Phase Electricity, high voltage, at grid/US U	Global Warming Contributed by Operational Phase Power	Embedded Global Warming	Total Global Warming
	kWh	g CO2 eq	g CO2 eq	g CO2 eq
Raw Water Pumping	1.64E+07	1.23E+10	2.46E+08	1.25E+10
Chemical_Alum	3.14E+05	2.35E+08	2.01E+10	2.03E+10
Chemical_Sulfuric	3.14E+05	2.35E+08	4.72E+09	4.96E+09
Coagulation	2.01E+06	1.50E+09	4.18E+08	1.92E+09
Sedimentation	1.06E+06	7.91E+08	7.36E+08	1.53E+09
Filtration	6.40E+05	4.79E+08	5.13E+08	9.92E+08
Chemical_Hypo	3.14E+05	2.35E+08	1.48E+10	1.51E+10
Chlorine Contact	8.14E+05	6.09E+08	3.80E+08	9.89E+08
Total	2.19E+07	1.64E+10	4.19E+10	5.83E+10



Intro | Help | Main | **Energy Analysis** | Raw Water Pumping | Chemical_Alum | Chemical_Sulfuric | Coag-Floc

LCI Database Summary

Material inventory summary, environmental impacts asscoiated with unit quantity of material and energy and total environmental impacts associated with the entire water treatment facility.



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LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 1
Raw Water Pumping

User Input

Plant Flow	mgd	10
Wet Well - Concrete		
Number of Wet Well	ea	2
Number of Redundant Wet Well	ea	0
Total Number of Wet Wells	ea	2
Pump Station Wet Well Retention Time	min	60
Volume Required	cf	56000
Side Water Depth	ft	15
Freeboard	ft	3
Total Wet Well Depth	ft	18
Length:Wdith Ratio		1:1
Basin Length	ft	44
Basin Width	ft	44
Basin Wall Thickness	in	16
Basin Bottom Slab Thickness	in	18
Basin Top Deck/Walkway Thickness	in	12
Common Wall Construction Between Trains		YES
Concrete Volume		
Wall	cy	200
Bottom Slab	cy	225
Top Deck	cy	140
Total Concrete Volume	cy	565
Design Rebar Quantity		
Wall	lb/sf	10
Bottom Slab	lb/sf	12
Top Deck	lb/sf	10
Rebar Steel Quantity		
Wall	ton	23.8
Bottom Slab	ton	24.3
Top Deck	ton	19.4
Total Rebar Steel	ton	67.4
Pumps		
Number of Duty Pumps	ea	2
Number of Redundant Pumps	ea	1
Total Number of Pumps	ea	3
Flow per Pump	mgd	5
Total Dynamic Head (TDH)	ft	50
Estimated Pump Costs	$	$19,722

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LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 1

Raw Water Pumping

Pumping Energy

Break Horsepower (BHP)		44
Efficiency		0.75
Motor Efficiency		0.95
Variable Frequency Drive (VFD) Efficiency		0.98
Motor Size	HP	63
Motor Size	KW	47
Run Time per Day	hr/day	24
Run Day per Week	day/week	7
Online Factor	%	100%
Power Consumption	kWh/year	819769
Electricity Cost	$/kwhr	0.08
Power Cost	$/year	$65,582
Piping and Misc.		
Pipe Length	ft	500
Maximum Design Velocity	fps	8
Pipe Diameter	inches	20
Type of Pipes		PVC_Schedule 80
Weight per Linear Foot	lb/lf	45.30
Total Pipe Weight	lb	22652

Module Inventory

Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 1

Raw Water Pumping

Process	Unit	Raw Influent PS
Equipment		
Pumps and compressors	USD	$19,722
Blowers and fans	USD	
Measuring and dispensing pumps	USD	
Conveyors and conveying equipment	USD	
Industrial trucks and tractors	USD	
Pipe, valves, and pipe fittings	USD	
Plumbing fixture fittings and trim	USD	
Turbines and turbine generator sets	USD	
Motors and generators	USD	
Water supply and sewerage systems	USD	
Material		
Reinforcing steel, at plant/RER U	kg	61,291
Concrete, normal, at plant/CH U	m3	432
Concrete (reinforced) I	kg	
Brick, at plant/RER U	kg	
Wood board ETH U	kg	
Sand ETH U	kg	
Hard coal mix, at regional storage/UCTE U	kg	
Gravel ETH U	kg	
HDPE pipes E	kg	
PVC pipe E	kg	10,296
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	kg	
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	kg	
Polyethylene, HDPE, granulate, at plant/RER U	kg	
St13 I - Material	kg	
Copper I - Material	kg	
Copper product manufacturing, average metal working/RER U	kg	
Aluminium, production mix, at plant/RER U - Material	kg	
Aluminium product manufacturing, average metal working/RER U - Processing	kg	
Chemical		
Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	kg	
Sodium hypochlorite, 15% in H2O, at plant/RER U	kg	
Lime, hydrated, packed, at plant/CH U	kg	

Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 1

Raw Water Pumping

Quicklime, milled, packed, at plant/CH U	kg	
Sulphuric acid, liquid, at plant/RER U	kg	
Aluminium sulphate, powder, at plant/RER U	kg	
Iron (III) chloride, 40% in H2O, at plant/CH U	kg	
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	kg	
Hydrochloric acid, 30% in H2O, at plant/RER U	kg	
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	kg	
Ammonium sulphate, as N, at regional storehouse/RER U	kg	
Energy		
Electricity, high voltage, at grid/US U (Life Cycle)	kWh	16,395,384
Natural gas, at consumer/RNA U	MJ	

Notes and Disclaimers:

1. This represents a conceptual level analysis. The structure was simplifed as shown below. No structural details such as special foundation requirements, piping penetrations, overflow, perforated walls, gates and valves were considered. Assume single wall thickness, slab thickness and deck thickness. This could be detailed in future phase of research.
2. No site specific civil site work was included in this analysis. No power supply infrastructure is included. No control and instruments were included.
3. The equipment costs included herein are based on generic equipment used for similar facility. Prices were not verified in this phase and should be further developed in future phases.
4. No residuals handling facility was included in the study boundary.

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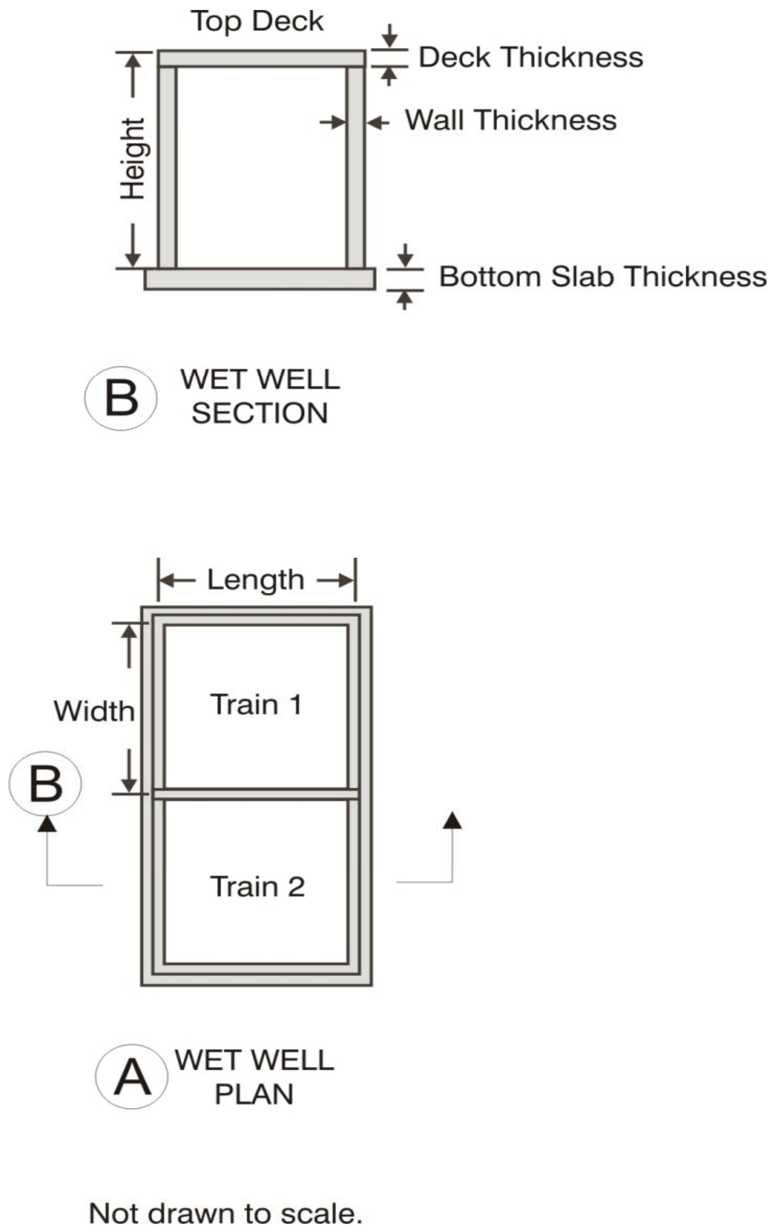
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 1
Raw Water Pumping



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LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 2
Chemical - Alum

User Input

Plant Flow	mgd	10
Chemical Description		
Type of Chemicals		Alum 50%
Dosage	mg/L	40
Design Storage	day	30
Concentration		50%
Specific Gravity		1.3
Chemical Usage	lb/day	6664
Chemical Usage	gallon per day	615
Run Time per Day	hr/day	24
Run Day per Week	day/week	7
Online Factor	%	100%
Chemical Usage	lb/year	2432360
Chemical Storage System		
Storage Volume	gallon	18439
Number of Duty Chemical Storage Tank	ea	2
Number of Redundant Storage Tank	ea	0
Total Number of Storage Tank	ea	2
Chemical Tank Diameter	ft	12
Chemical Tank Height (excluding freeboard)	ft	11
Chemical Storage Tank Volume	gallons	10000
Chemical Storage Tank Material		Fiber Glass
Total Material Weight	lb	7000
Chemical Metering Pumps		
Number of Duty Metering Pumps	ea	1
Number of Redundant Metering Pumps	ea	1
Total Number of Metering Pumps	ea	2
Estimated Total Chemical Metering Pump and Misc. Equipment Costs	$	$5,000
Energy Consumption		
Misc Equipment Size	HP	0.2
Misc Equipment Size	KW	0.1
Run Time per Day	hr/day	24
Run Day per Week	day/week	7
Online Factor	%	100%
Power Consumption	kWh/year	15678
Electricity Cost	$/kwhr	0.08
Power Cost	$/year	$1,254

Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 2
Chemical - Alum

Chemical Containment Area		
Containment Area Depth	ft	6
Containment Area Width	ft	18
Containment Area Length	ft	19
Wall Thickness	in	16
Bottom Slab Thickness	in	18
Concrete Volume		
Wall	cy	22
Bottom Slab	cy	21
Total Concrete Volume	cy	42
Design Rebar Quantity		
Wall	lb/sf	10
Bottom Slab	lb/sf	12
Rebar Steel Quantity		
Wall	ton	2.2
Bottom Slab	ton	2.0
Total Rebar Steel	ton	4.2

Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 2

Chemical - Alum

Module Inventory

Process	Unit	Chemical
Equipment		
Pumps and compressors	USD	
Blowers and fans	USD	
Measuring and dispensing pumps	USD	$5,000
Conveyors and conveying equipment	USD	
Industrial trucks and tractors	USD	
Pipe, valves, and pipe fittings	USD	
Plumbing fixture fittings and trim	USD	
Turbines and turbine generator sets	USD	
Motors and generators	USD	
Water supply and sewerage systems	USD	
Material		
Reinforcing steel, at plant/RER U	kg	3
Concrete, normal, at plant/CH U	m3	38,477
Concrete (reinforced) I	kg	
Brick, at plant/RER U	kg	
Wood board ETH U	kg	
Sand ETH U	kg	
Hard coal mix, at regional storage/UCTE U	kg	
Gravel ETH U	kg	
HDPE pipes E	kg	
PVC pipe E	kg	
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	kg	
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	kg	3,182
Polyethylene, HDPE, granulate, at plant/RER U	kg	
St13 I - Material	kg	
Copper I - Material	kg	
Copper product manufacturing, average metal working/RER U	kg	
Aluminium, production mix, at plant/RER U - Material	kg	
Aluminium product manufacturing, average metal working/RER U - Processing	kg	
Chemical		
Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	kg	

Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 2

Chemical - Alum

Sodium hypochlorite, 15% in H2O, at plant/RER U	kg	
Lime, hydrated, packed, at plant/CH U	kg	
Quicklime, milled, packed, at plant/CH U	kg	
Sulphuric acid, liquid, at plant/RER U	kg	
Aluminium sulphate, powder, at plant/RER U	kg	22,112,364
Iron (III) chloride, 40% in H2O, at plant/CH U	kg	
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	kg	
Hydrochloric acid, 30% in H2O, at plant/RER U	kg	
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	kg	
Ammonium sulphate, as N, at regional storehouse/RER U	kg	
Energy		
Electricity, high voltage, at grid/US U (Life Cycle)	kWh	313,552
Natural gas, at consumer/RNA U	MJ	

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Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 3

Chemical - Sulfuric Acid

User Input

Plant Flow	mgd	10
Chemical Description		
Type of Chemicals		Sulfuric Acid 93%
Dosage	mg/L	20
Design Storage	day	30
Concentration		93%
Specific Gravity		1.84
Chemical Usage	lb/day	1791.397849
Chemical Usage	gallon per day	117
Run Time per Day	hr/day	24
Run Day per Week	day/week	7
Online Factor	%	100%
Chemical Usage	lb/year	653860
Chemical Storage System		
Storage Volume		3502
Number of Duty Chemical Storage Tank	ea	2
Number of Redundant Storage Tank	ea	0
Total Number of Storage Tank	ea	2
Chemical Tank Diameter	ft	12
Chemical Tank Height (excluding freeboard)	ft	2
Chemical Storage Tank Volume	gallons	2000
Chemical Storage Tank Material		Fiber Glass
Total Material Weight	lb	1400
Chemical Metering Pumps		
Number of Duty Metering Pumps	ea	1
Number of Redundant Metering Pumps	ea	1
Total Number of Metering Pumps	ea	2
Estimated Total Chemical Metering Pump and Misc. Equipment Costs	$	$5,000
Energy Consumption		
Misc Equipment Size	HP	0.2
Misc Equipment Size	KW	0.1
Run Time per Day	hr/day	24
Run Day per Week	day/week	7
Online Factor	%	100%
Power Consumption	kWh/year	15678
Electricity Cost	$/kwhr	0.08
Power Cost	$/year	$1,254

Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 3
Chemical - Sulfuric Acid

Chemical Containment Area		
Containment Area Depth	ft	6
Containment Area Width	ft	18
Containment Area Length	ft	4
Wall Thickness	in	16
Bottom Slab Thickness	in	18
Concrete Volume		
Wall	cy	13
Bottom Slab	cy	5
Total Concrete Volume	cy	18
Design Rebar Quantity		
Wall	lb/sf	10
Bottom Slab	lb/sf	12
Rebar Steel Quantity		
Wall	ton	1.3
Bottom Slab	ton	0.4
Total Rebar Steel	ton	1.7

Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 3
Chemical - Sulfuric Acid

Module Inventory

Process	Unit	Chemical
Equipment		
Pumps and compressors	USD	
Blowers and fans	USD	
Measuring and dispensing pumps	USD	$5,000
Conveyors and conveying equipment	USD	
Industrial trucks and tractors	USD	
Pipe, valves, and pipe fittings	USD	
Plumbing fixture fittings and trim	USD	
Turbines and turbine generator sets	USD	
Motors and generators	USD	
Water supply and sewerage systems	USD	
Material		
Reinforcing steel, at plant/RER U	kg	1
Concrete, normal, at plant/CH U	m3	16,221
Concrete (reinforced) I	kg	
Brick, at plant/RER U	kg	
Wood board ETH U	kg	
Sand ETH U	kg	
Hard coal mix, at regional storage/UCTE U	kg	
Gravel ETH U	kg	
HDPE pipes E	kg	
PVC pipe E	kg	
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	kg	
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	kg	636
Polyethylene, HDPE, granulate, at plant/RER U	kg	
St13 I - Material	kg	
Copper I - Material	kg	
Copper product manufacturing, average metal working/RER U	kg	
Aluminium, production mix, at plant/RER U - Material	kg	
Aluminium product manufacturing, average metal working/RER U - Processing	kg	
Chemical		

Module 3
Chemical - Sulfuric Acid

Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	kg	
Sodium hypochlorite, 15% in H2O, at plant/RER U	kg	
Lime, hydrated, packed, at plant/CH U	kg	
Quicklime, milled, packed, at plant/CH U	kg	
Sulphuric acid, liquid, at plant/RER U	kg	5,944,184
Aluminium sulphate, powder, at plant/RER U	kg	
Iron (III) chloride, 40% in H2O, at plant/CH U	kg	
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	kg	
Hydrochloric acid, 30% in H2O, at plant/RER U	kg	
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	kg	
Ammonium sulphate, as N, at regional storehouse/RER U	kg	
Energy		
Electricity, high voltage, at grid/US U (Life Cycle)	kWh	313,552
Natural gas, at consumer/RNA U	MJ	

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Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 4
Coagulation Flocculation

User Input

Plant Flow	mgd	10
Rapid Mix Chamber- Concrete		
Number of Rapid Mix	ea	1
Number of Redundant Rapid Mix	ea	1
Total Number of Rapid Mix	ea	2
Rapid Mix Retention Time	min	1
Volume Required	cf	930
Side Water Depth	ft	14
Freeboard	ft	2
Total Rapid Mix Depth	ft	16
Length:Wdith Ratio		1:1
Basin Length	ft	8
Basin Width	ft	8
Basin Wall Thickness	in	16
Basin Bottom Slab Thickness	in	18
Basin Top Deck/Walkway Thickness	in	12
Common Wall Construction Between Trains		YES
Concrete Volume		
Wall	cy	32
Bottom Slab	cy	9
Top Deck	cy	5
Total Concrete Volume	cy	46
Design Rebar Quantity		
Wall	lb/sf	10
Bottom Slab	lb/sf	12
Top Deck	lb/sf	10
Rebar Steel Quantity		
Wall	ton	3.3
Bottom Slab	ton	1.0
Top Deck	ton	0.7
Total Rebar Steel	ton	4.9
Mixers		
Number of Duty Mixers	ea	1
Number of Redundant Mixer	ea	1
Total Number of Mixers	ea	2
Viscosity(µ)	lbf-sec/sf	0.000018
G Value	1/s	500
P=G^2*V*µ	ft-lbf/sec	4185

Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 4

Coagulation Flocculation

Estimated Mixer Costs	$	$64,000
Mixer Energy		
Break Horsepower (BHP)	HP	8
Efficiency		0.65
Motor Efficiency		0.95
Motor Size	HP	12
Motor Size	KW	9
Run Time per Day	hr/day	24
Run Day per Week	day/week	7
Online Factor	%	100%
Power Consumption	kWh/year	80494
Electricity Cost	$/kwhr	0.08
Power Cost	$/year	$6,440
Flocculation Tank - Concrete		
Type of Flocculation Tank		Vertical, 3-Stage, Concrete
Number of Flocculation Tank	ea	1
Number of Redundant Flocculation Tank	ea	1
Total Number of Flocculation Tank	ea	2
Flocculation Tank Retention Time	min	30
Volume Required	cf	27835
Side Water Depth	ft	14
Freeboard	ft	2
Total Flocculation Tank Depth	ft	16
Length:Wdith Ratio		1:3
Basin Length	ft	77
Basin Width	ft	26
Basin Wall Thickness	in	16
Basin Bottom Slab Thickness	in	18
Separation Wall Thickness	in	16
Basin Top Deck/Walkway Thickness	in	12
Basin Top Walkway Width	ft	5
Number of Stages	ea	3
Number of Separation Wall per Train		2
Common Wall Construction Between Trains		YES
Concrete Volume		
Basin Wall	cy	264
Bottom Slab	cy	232
Top Walkway	cy	5
Separation Wall Between Stages	cy	81
Total Concrete Volume	cy	582
Design Rebar Quantity		

Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 4

Coagulation Flocculation

Wall	lb/sf	10
Bottom Slab	lb/sf	12
Top Walkway	lb/sf	10
Separation Wall	lb/sf	10
Rebar Steel Quantity		
Wall	ton	26.8
Bottom Slab	ton	25.1
Top Walkway	ton	7.7
Separation Wall	ton	8.2
Total Rebar Steel	ton	60
Flocculator		
Number of Duty Flocculators	ea	1
Number of Redundant Flocculators	ea	1
Total Number of Flocculators	ea	2
Viscosity(μ)	lbf-sec/sf	0.000021
Stage 1 G Value	1/s	35
Stage 2 G Value	1/s	21
Stage 3 G Value	1/s	10
Stage 1 P=G^2*V*μ	ft-lbf/sec	716
Stage 2 P=G^2*V*μ	ft-lbf/sec	258
Stage 3 P=G^2*V*μ	ft-lbf/sec	58
Estimated Flocculator Costs	$	$190,000
Stage 1 Flocculator		
Break Horsepower (BHP)	HP	1.3
Efficiency		0.65
Motor Efficiency		0.95
Motor Size	HP	2.11
Motor Size	KW	1.57
Run Time per Day	hr/day	24
Run Day per Week	day/week	7
Online Factor	%	100%
Power Consumption	kWh/year	13773
Electricity Cost	$/kwhr	0.08
Power Cost	$/year	$1,102
Stage 2 Flocculator		
Break Horsepower (BHP)	HP	0.5
Efficiency		0.65
Motor Efficiency		0.95
Motor Size	HP	0.76
Motor Size	KW	0.57
Run Time per Day	hr/day	24
Run Day per Week	day/week	7
Online Factor	%	100%

Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 4
Coagulation Flocculation

Power Consumption	kWh/year	4958
Electricity Cost	$/kwhr	0.08
Power Cost	$/year	$397
Stage 3 Flocculator		
Break Horsepower (BHP)	HP	0.11
Efficiency		0.65
Motor Efficiency		0.95
Motor Size	HP	0.17
Motor Size	KW	0.13
Run Time per Day	hr/day	24
Run Day per Week	day/week	7
Online Factor	%	100%
Power Consumption	kWh/year	1124
Electricity Cost	$/kwhr	0.08
Power Cost	$/year	$90
Piping and Misc.		
Pipe Length	ft	100
Maximum Design Velocity	fps	8
Pipe Diameter	inches	20
Type of Pipes		PVC_Schedule 40
Weight per Linear Foot	lb/lf	45.30
Total Pipe Weight	lb	4530

Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 4

Coagulation Flocculation

Module Inventory

Process	**Unit**	**Coag-Flocc**
Equipment		
Pumps and compressors	USD	$254,000
Blowers and fans	USD	
Measuring and dispensing pumps	USD	
Conveyors and conveying equipment	USD	
Industrial trucks and tractors	USD	
Pipe, valves, and pipe fittings	USD	
Plumbing fixture fittings and trim	USD	
Turbines and turbine generator sets	USD	
Motors and generators	USD	
Water supply and sewerage systems	USD	
Material		
Reinforcing steel, at plant/RER U	kg	58,665
Concrete, normal, at plant/CH U	m3	480
Concrete (reinforced) I	kg	
Brick, at plant/RER U	kg	
Wood board ETH U	kg	
Sand ETH U	kg	
Hard coal mix, at regional storage/UCTE U	kg	
Gravel ETH U	kg	
HDPE pipes E	kg	
PVC pipe E	kg	2,059
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	kg	
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	kg	
Polyethylene, HDPE, granulate, at plant/RER U	kg	
St13 I - Material	kg	
Copper I - Material	kg	
Copper product manufacturing, average metal working/RER U	kg	
Aluminium, production mix, at plant/RER U - Material	kg	
Aluminium product manufacturing, average metal working/RER U - Processing	kg	
Chemical		

Module 4
Coagulation Flocculation

Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	kg	
Sodium hypochlorite, 15% in H2O, at plant/RER U	kg	
Lime, hydrated, packed, at plant/CH U	kg	
Quicklime, milled, packed, at plant/CH U	kg	
Sulphuric acid, liquid, at plant/RER U	kg	
Aluminium sulphate, powder, at plant/RER U	kg	
Iron (III) chloride, 40% in H2O, at plant/CH U	kg	
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	kg	
Hydrochloric acid, 30% in H2O, at plant/RER U	kg	
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	kg	
Ammonium sulphate, as N, at regional storehouse/RER U	kg	
Energy		
Electricity, high voltage, at grid/US U (Life Cycle)	kWh	2,006,982
Natural gas, at consumer/RNA U	MJ	

Notes and Disclaimers:

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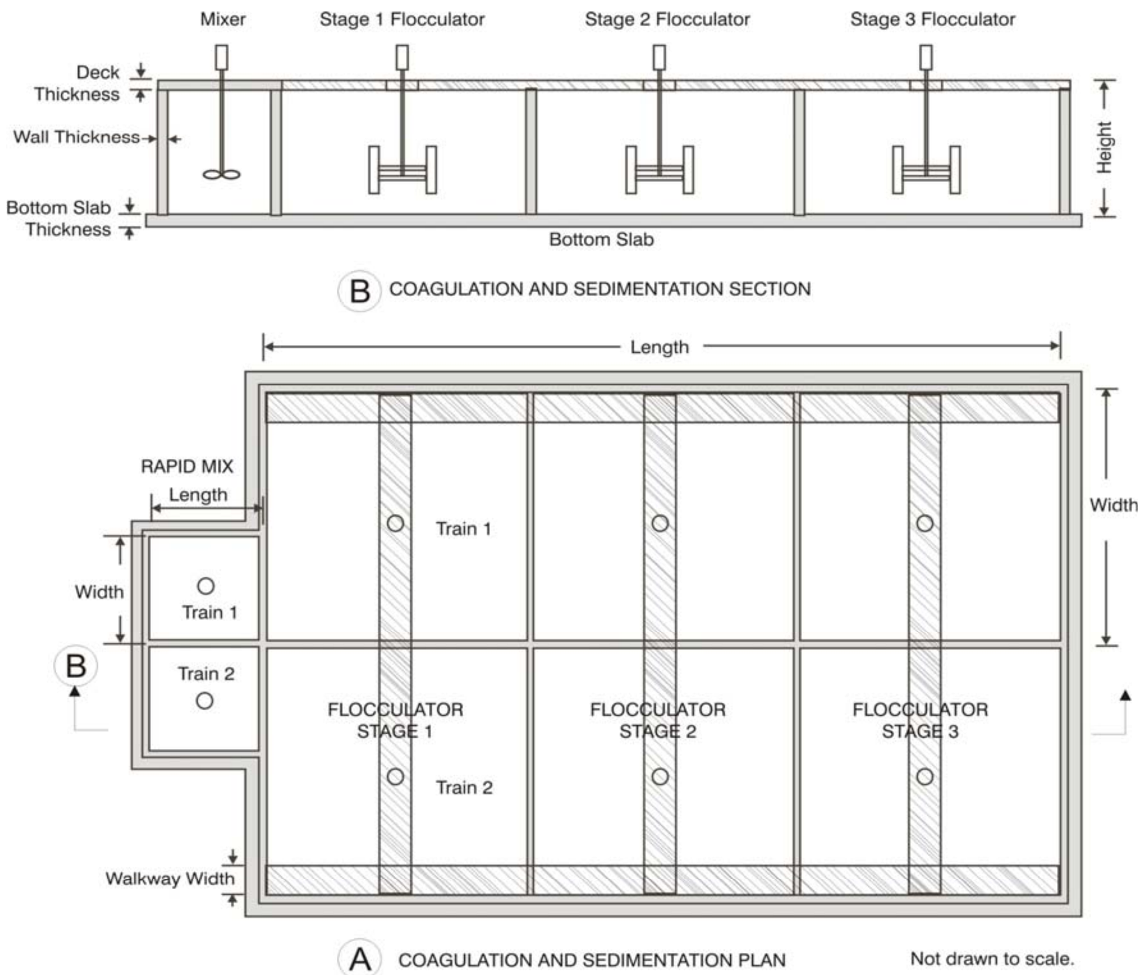
4. No residuals handling facility was included in the study boundary.

Module 4
Coagulation Flocculation



A COAGULATION AND SEDIMENTATION PLAN

Not drawn to scale.

Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 5

Sedimentation

Plant Flow	mgd	10

Type of Sedimentation ( ) Circular Concrete (•) Rectangular Concrete

Sedimentation - Concrete Rectangular		
Number of Sedimentation Basins	ea	1
Number of Redundant Sedimentation Basins	ea	1
Total Number of Sedimentation Basins	ea	2
Sedimentation Basins Retention Time	min	120
Volume Required	cf	111340
Surface Loading Rate	gpm/sf	0.72
Surface Area Required	sf	9640
Side Water Depth	ft	14
Freeboard	ft	2
Total Sedimentation Basin Depth	ft	16
Length:Wdith Ratio		1:1
Basin Length	ft	100
Basin Width	ft	100
Actual Surface Area	sf	10000
Actual Retention Time	min	151
Basin Wall Thickness	in	16
Basin Bottom Slab Thickness	in	18
Basin Top Walkway Width	ft	5
Basin Top Deck/Walkway Thickness	in	12
Common Wall Construction Between Trains		YES
Concrete Volume		
Wall	cy	400
Bottom Slab	cy	1130
Top Walkway	cy	74
Total Concrete Volume	cy	1604
Design Rebar Quantity		
Wall	lb/sf	10
Bottom Slab	lb/sf	12
Top Walkway	lb/sf	10
Rebar Steel Quantity		
Wall	ton	40.0
Bottom Slab	ton	122.4
Top Walkway	ton	10.0
Total Rebar Steel	ton	172.4

Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 5
Sedimentation

Weir Trough

Type of Material		FRP
Design Weir Loading	gpm/ft	10
Length of Troughs	ft	347
Depth of Troughs	ft	3
Width of Troughs	ft	4
Thickness of Material	in	0.25
Density of Material	lb/cf	116
Estimated Total FRP Weight per ft	lb	18413

Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 5
Sedimentation

Sludge Scrapper		
Number of Duty Scrapper	ea	1
Number of Redundant Scrapper	ea	1
Total Number of Scrapper	ea	2
Estimated Mixer Costs	$	$190,000
Mixer Energy		
Break Horsepower (BHP) for All Trains	HP	5
Efficiency		0.65
Motor Efficiency		0.95
Motor Size	HP	8
Motor Size	KW	6
Run Time per Day	hr/day	24
Run Day per Week	day/week	7
Online Factor	%	100%
Power Consumption	kWh/year	52893
Electricity Cost	$/kwhr	0.08
Power Cost	$/year	$4,231
Piping and Misc.		
Pipe Length	ft	100
Maximum Design Velocity	fps	8
Pipe Diameter	inches	20
Type of Pipes		PVC_Schedule 40
Weight per Linear Foot	lb/lf	45.30
Total Pipe Weight	lb	4530

Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 5
Sedimentation

Module Inventory

Process	Unit	Sedimentation
Equipment		
Pumps and compressors	USD	$190,000
Blowers and fans	USD	
Measuring and dispensing pumps	USD	
Conveyors and conveying equipment	USD	
Industrial trucks and tractors	USD	
Pipe, valves, and pipe fittings	USD	
Plumbing fixture fittings and trim	USD	
Turbines and turbine generator sets	USD	
Motors and generators	USD	
Water supply and sewerage systems	USD	
Material		
Reinforcing steel, at plant/RER U	kg	156,738
Concrete, normal, at plant/CH U	m3	1,226
Concrete (reinforced) I	kg	
Brick, at plant/RER U	kg	
Wood board ETH U	kg	
Sand ETH U	kg	
Hard coal mix, at regional storage/UCTE U	kg	
Gravel ETH U	kg	
HDPE pipes E	kg	
PVC pipe E	kg	2,059
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	kg	
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	kg	8,370
Polyethylene, HDPE, granulate, at plant/RER U	kg	
St13 I - Material	kg	
Copper I - Material	kg	
Copper product manufacturing, average metal working/RER U	kg	
Aluminium, production mix, at plant/RER U - Material	kg	
Aluminium product manufacturing, average metal working/RER U - Processing	kg	
Chemical		

Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 5
Sedimentation

Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	kg	
Sodium hypochlorite, 15% in H2O, at plant/RER U	kg	
Lime, hydrated, packed, at plant/CH U	kg	
Quicklime, milled, packed, at plant/CH U	kg	
Sulphuric acid, liquid, at plant/RER U	kg	
Aluminium sulphate, powder, at plant/RER U	kg	
Iron (III) chloride, 40% in H2O, at plant/CH U	kg	
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	kg	
Hydrochloric acid, 30% in H2O, at plant/RER U	kg	
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	kg	
Ammonium sulphate, as N, at regional storehouse/RER U	kg	
Energy		
Electricity, high voltage, at grid/US U (Life Cycle)	kWh	1,057,868
Natural gas, at consumer/RNA U	MJ	

Notes and Disclaimers:

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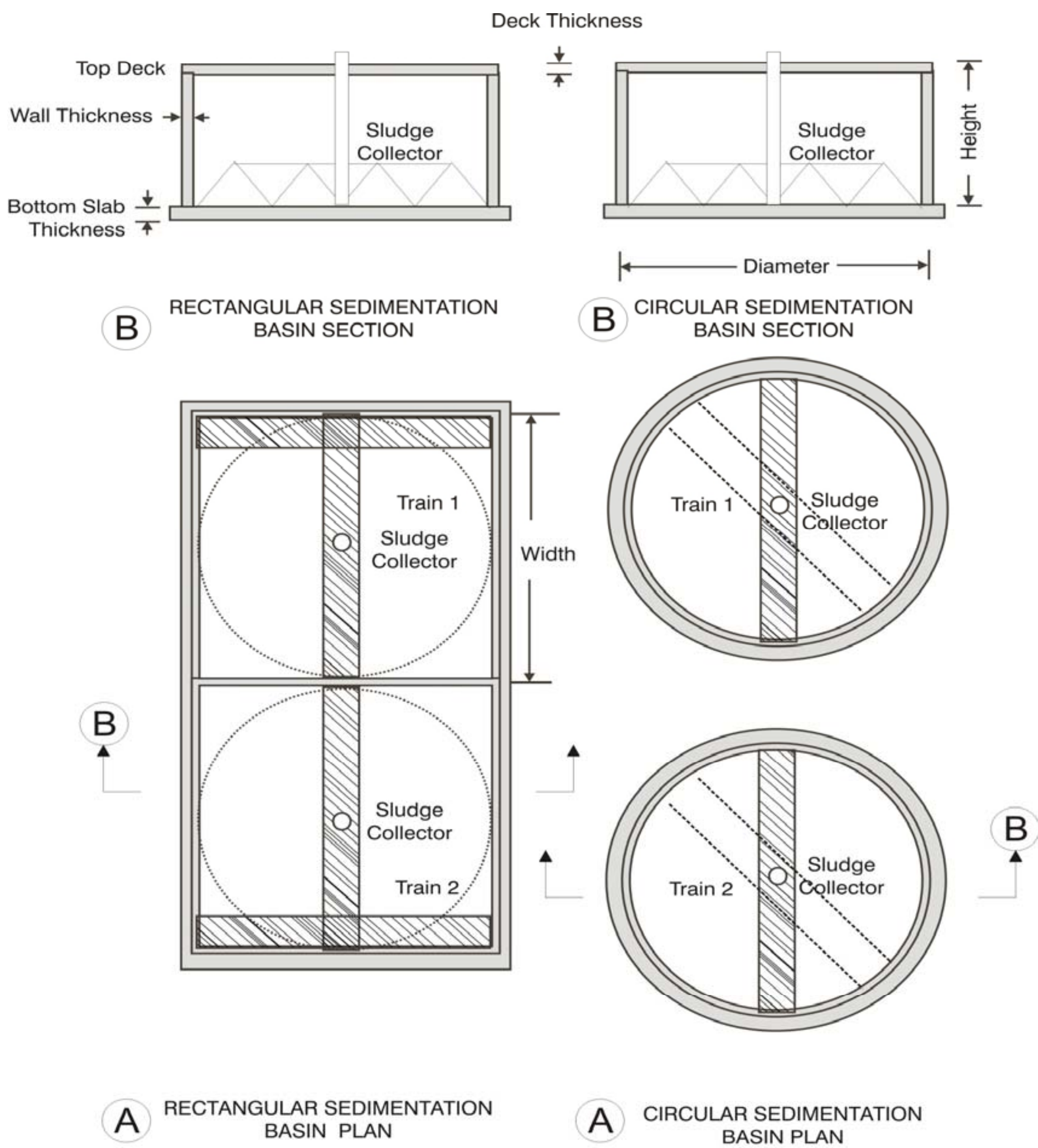
Module 5
Sedimentation



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Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 6
Filtration

User Input

Plant Flow	mgd	10	
Type of Filter Box		Rectangular Concrete	
Type of Filter Media		Dual Media	
Filter - Concrete			
Number of Duty Filters	ea	4	(min 4)
Number of Redundant Filters	ea	1	
Total Number of Filters	ea	5	
Surface Loading Rate	gpm/sf	6	
Surface Area Required	sf	1160	
Side Water Depth	ft	18	
Freeboard	ft	2	
Total Filter Depth	ft	20	
Length:Wdith Ratio		1:2	
Basin Length	ft	25	
Basin Width	ft	13	
Actual Surface Area	sf	1300	
Basin Wall Thickness	in	16	
Basin Bottom Slab Thickness	in	18	
Basin Top Walkway Width	ft	5	
Basin Top Deck/Walkway Thickness	in	12	
Common Wall Construction Between Trains		YES	
Concrete Volume			
Wall	cy	212	
Bottom Slab	cy	101	
Top Walkway	cy	23	
Total Concrete Volume	cy	336	
Design Rebar Quantity			
Wall	lb/sf	10	
Bottom Slab	lb/sf	12	
Top Walkway	lb/sf	10	
Rebar Steel Quantity			
Wall	ton	21.5	
Bottom Slab	ton	10.9	
Top Walkway	ton	3.1	
Total Rebar Steel	ton	35.5	
Backwash Troughs			
Type of Material		FRP	
Design Weir Loading	gpm/ft	20	
Number of Troughs	ea	2	

Actual Weir Loading	gpm/ft	17.4
Depth of Troughs	ft	3
Width of Troughs	ft	3
Thickness of Material	in	0.25
Density of Material	lb/cf	116
Estimated Total FRP Weight per Trough	lb	597
Total FRP Weight	lb	5970
Filter Media		
Type of Media		Dual Media
Depth of Media		
Anthracite	in	24
Sand	in	12
Gravel	in	6
Density of Media		
Anthracite	lb/cf	50
Sand	lb/cf	115
Gravel	lb/cf	100
Volume of Media		
Anthracite	cf	3250
Sand	cf	1625
Gravel	cf	812.5
Weight of Media		
Anthracite	lb	162500
Sand	lb	186875
Gravel	lb	81250
Meida Replacement Frequency	years	10
Replacement During Life Cycle		2
Total Weight during Life Cycle		
Anthracite	lb	325000
Sand	lb	373750
Gravel	lb	162500
Type Underdrain		MSCap Type S
Length, in		48
Width, in		11
Height, in		12
Weight, lb		25
HDEP Material Weight	lb	276989
Backwash Pumps		
Number of Duty Pumps	ea	1
Number of Redundant Pumps	ea	1
Total Number of Pumps	ea	2
Design Backwash Surface Loading Rate	gpm/sf	20
Backwash Flow Rate	gpm	6500
Flow per Pump	mgd	9.37
TDH	ft	25
Estimated Pump Costs	$	$12,395
Compressor and Air Blower Equipment Cos	$	$18,593
Pumping Energy		
Break Horsepower (BHP)		41

Efficiency		0.75
Motor Efficiency		0.95
VFD Efficiency		0.98
Motor Size	HP	59
Motor Size	KW	44
Run Time per Day	hr/day	1.3
Run Day per Week	day/week	7
Online Factor	%	6%
Power Consumption	kWh/year	21328
Total Power Including Compressor	kWh/year	31991
Electricity Cost	$/kwhr	0.08
Power Cost	$/year	$2,559
Piping and Misc.		
Pipe Length	ft	200
Maximum Design Velocity	fps	8
Pipe Diameter	inches	20
Type of Pipes		PVC_Schedule 40
Weight per Linear Foot	lb/lf	45.30
Total Pipe Weight	lb	9061

Module Inventory

Process	Unit	Filtration
Equipment		
Pumps and compressors	USD	$12,395
Blowers and fans	USD	$18,593
Measuring and dispensing pumps	USD	
Conveyors and conveying equipment	USD	
Industrial trucks and tractors	USD	
Pipe, valves, and pipe fittings	USD	
Plumbing fixture fittings and trim	USD	
Turbines and turbine generator sets	USD	
Motors and generators	USD	
Water supply and sewerage systems	USD	
Material		
Reinforcing steel, at plant/RER U	kg	32,314
Concrete, normal, at plant/CH U	m3	257
Concrete (reinforced) I	kg	
Brick, at plant/RER U	kg	
Wood board ETH U	kg	
Sand ETH U	kg	169,886
Hard coal mix, at regional storage/UCTE U	kg	147,727
Gravel ETH U	kg	73,864
HDPE pipes E	kg	125,904
PVC pipe E	kg	4,119
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	kg	
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	kg	2,714
Polyethylene, HDPE, granulate, at	kg	
St13 I - Material	kg	
Copper I - Material	kg	
Copper product manufacturing, average metal working/RER U	kg	
Aluminium, production mix, at plant/RER U -	kg	
Aluminium product manufacturing, average metal working/RER U - Processing	kg	
Chemical		
Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	kg	
Sodium hypochlorite, 15% in H2O, at	kg	
Lime, hydrated, packed, at plant/CH U	kg	
Quicklime, milled, packed, at plant/CH U	kg	
Sulphuric acid, liquid, at plant/RER U	kg	
Aluminium sulphate, powder, at plant/RER U	kg	
Iron (III) chloride, 40% in H2O, at plant/CH U	kg	
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	kg	

Hydrochloric acid, 30% in H2O, at plant/RER	kg	
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	kg	
Ammonium sulphate, as N, at regional storehouse/RER U	kg	
Energy		
Electricity, high voltage, at grid/US U (Life	kWh	639,829
Natural gas, at consumer/RNA U	MJ	

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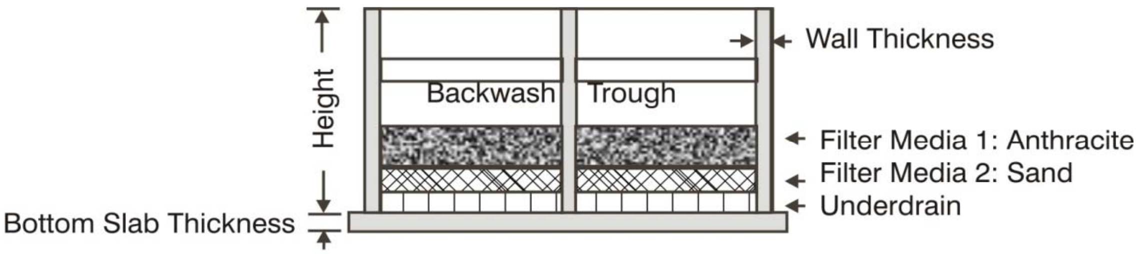
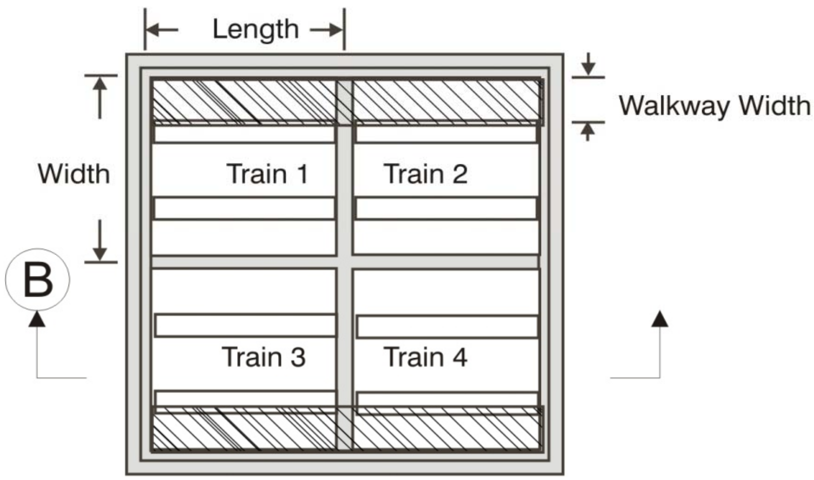


B FILTER SECTION



A FILTER PLAN

Not drawn to scale.

Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 7
Sodium Hypochlorite

User Input

Plant Flow	mgd	10
Chemical Description		
Type of Chemicals		Sodium Hypochlorite 12.5%
Dosage	mg/L	5
Design Storage	day	30
Concentration		13%
Specific Gravity		1.2
Chemical Usage	lb/day	3332
Chemical Usage	gallon per day	333
Run Time per Day	hr/day	24
Run Day per Week	day/week	7
Online Factor	%	100%
Chemical Usage	lb/year	1216180
Chemical Storage System		
Storage Volume		9988
Number of Duty Chemical Storage Tank	ea	2
Number of Redundant Storage Tank	ea	0
Total Number of Storage Tank	ea	2
Chemical Tank Diameter	ft	12
Chemical Tank Height (excluding freeboard)	ft	6
Chemical Storage Tank Volume	gallons	5000
Chemical Storage Tank Material		Fiber Glass
Total Material Weight	lb	3500
Chemical Metering Pumps		
Number of Duty Metering Pumps	ea	1
Number of Redundant Metering Pumps	ea	1
Total Number of Metering Pumps	ea	2
Estimated Total Chemical Metering Pump and Misc. Equipment Costs	$	$5,000
Energy Consumption		
Misc Equipment Size	HP	0.2
Misc Equipment Size	KW	0.1
Run Time per Day	hr/day	24
Run Day per Week	day/week	7
Online Factor	%	100%
Power Consumption	kWh/year	15678
Electricity Cost	$/kwhr	0.08
Power Cost	$/year	$1,254

Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 7
Sodium Hypochlorite

Chemical Containment Area		
Containment Area Depth	ft	6
Containment Area Width	ft	18
Containment Area Length	ft	9
Wall Thickness	in	16
Bottom Slab Thickness	in	18
Concrete Volume		
Wall	cy	16
Bottom Slab	cy	11
Total Concrete Volume	cy	27
Design Rebar Quantity		
Wall	lb/sf	10
Bottom Slab	lb/sf	12
Rebar Steel Quantity		
Wall	ton	1.6
Bottom Slab	ton	1.0
Total Rebar Steel	ton	2.6

Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 7

Sodium Hypochlorite

Module Inventory

Process	Unit	Chemical
Equipment		
Pumps and compressors	USD	
Blowers and fans	USD	
Measuring and dispensing pumps	USD	$5,000
Conveyors and conveying equipment	USD	
Industrial trucks and tractors	USD	
Pipe, valves, and pipe fittings	USD	
Plumbing fixture fittings and trim	USD	
Turbines and turbine generator sets	USD	
Motors and generators	USD	
Water supply and sewerage systems	USD	
Material		
Reinforcing steel, at plant/RER U	kg	2
Concrete, normal, at plant/CH U	m3	24,567
Concrete (reinforced) I	kg	
Brick, at plant/RER U	kg	
Wood board ETH U	kg	
Sand ETH U	kg	
Hard coal mix, at regional storage/UCTE U	kg	
Gravel ETH U	kg	
HDPE pipes E	kg	
PVC pipe E	kg	
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	kg	
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	kg	1,591
Polyethylene, HDPE, granulate, at plant/RER U	kg	
St13 I - Material	kg	
Copper I - Material	kg	
Copper product manufacturing, average metal working/RER U	kg	
Aluminium, production mix, at plant/RER U - Material	kg	
Aluminium product manufacturing, average metal working/RER U - Processing	kg	
Chemical		
Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	kg	

Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 7

Sodium Hypochlorite

Sodium hypochlorite, 15% in H2O, at plant/RER U	kg	11,056,182
Lime, hydrated, packed, at plant/CH U	kg	
Quicklime, milled, packed, at plant/CH U	kg	
Sulphuric acid, liquid, at plant/RER U	kg	
Aluminium sulphate, powder, at plant/RER U	kg	
Iron (III) chloride, 40% in H2O, at plant/CH U	kg	
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	kg	
Hydrochloric acid, 30% in H2O, at plant/RER U	kg	
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	kg	
Ammonium sulphate, as N, at regional storehouse/RER U	kg	
Energy		
Electricity, high voltage, at grid/US U (Life Cycle)	kWh	313,552
Natural gas, at consumer/RNA U	MJ	

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Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 8
Chlorine Contact Basin

User Input

Plant Flow	mgd	10
Type of Chlorine Contact Basin		Rectangular Concrete
Chlorine Contact Basins - Concrete		
Number of Chlorine Contact Basin	ea	1
Number of Redundant Chlorine Contact Basin	ea	1
Total Number of Chlorine Contact Basin	ea	2
Chlorine Contact Basin Retention Time	min	30
Volume Required	cf	28000
Side Water Depth	ft	14
Freeboard	ft	2
Total Chlorine Contact Basin Depth	ft	16
Length:Wdith Ratio		1:1
Basin Length	ft	45
Basin Width	ft	45
Basin Wall Thickness	in	16
Basin Bottom Slab Thickness	in	18
Basin Top Deck Thickness	in	12
Baffle Wall Thickness	in	12
Design Width of Each Flow Channel	ft	5
Number of Baffle Wall		8
Common Wall Construction Between Trains		YES
Concrete Volume		
Wall	cy	178
Bottom Slab	cy	235
Concrete Cover	cy	150
Baffle Wall	cy	379
Total Concrete Volume	cy	942
Design Rebar Quantity		
Wall	lb/sf	10
Bottom Slab	lb/sf	12
Concrete Cover	lb/sf	10
Baffle Wall	lb/sf	10
Rebar Steel Quantity		
Wall	ton	18.0
Bottom Slab	ton	25.4
Concrete Cover	ton	20.3
Baffle Wall	ton	51.2

Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 8
Chlorine Contact Basin

Total Rebar Steel	ton	114.8
Rapid Mix Chamber- Concrete		
Number of Rapid Mix	ea	1
Number of Redundant Rapid Mix	ea	1
Total Number of Rapid Mix	ea	2
Rapid Mix Retention Time	min	0.5
Volume Required	cf	470
Side Water Depth	ft	14
Freeboard	ft	2
Total Rapid Mix Depth	ft	16
Length:Wdith Ratio		1:1
Basin Length	ft	6
Basin Width	ft	6
Basin Wall Thickness	in	16
Basin Bottom Slab Thickness	in	18
Basin Top Deck/Walkway Thickness	in	12
Common Wall Construction Between Trains		YES
Concrete Volume		
Wall	cy	32
Bottom Slab	cy	9
Top Deck	cy	2
Total Concrete Volume	cy	43
Design Rebar Quantity		
Wall	lb/sf	10
Bottom Slab	lb/sf	12
Top Deck	lb/sf	10
Rebar Steel Quantity		
Wall	ton	3.3
Bottom Slab	ton	1.0
Top Deck	ton	0.7
Total Rebar Steel	ton	4.9
Mixers		
Number of Duty Mixers	ea	1
Number of Redundant Mixer	ea	1
Total Number of Mixers	ea	2
Viscosity(μ)	lbf-sec/sf	0.000018
G Value	1/s	500
P=G^2*V*μ	ft-lbf/sec	2115
Estimated Mixer Costs	$	$32,000.00
Mixer Energy		
Break Horsepower (BHP)	HP	4
Efficiency		0.65

Water Research Foundation

LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 8

Chloine Contact Basin

Motor Efficiency		0.95
Motor Size	HP	6
Motor Size	KW	5
Run Time per Day	hr/day	24
Run Day per Week	day/week	7
Online Factor	%	100%
Power Consumption	kWh/year	40680
Electricity Cost	$/kwhr	0.08
Power Cost	$/year	$3,254
Piping and Misc.		
Pipe Length	ft	100
Maximum Design Velocity	fps	8
Pipe Diameter	inches	20
Type of Pipes		PVC_Schedule 40
Weight per Linear Foot	lb/lf	45.30
Total Pipe Weight	lb	4530

Water Research Foundation
LIFE CYCLE INVENTORY AND LIFE CYCLE IMPACT ASSESSMENT DATABASE

Module 8
Chlorine Contact Basin

Module Inventory

Process	Unit	Chlorine Contact
Equipment		
Pumps and compressors	USD	$32,000
Blowers and fans	USD	
Measuring and dispensing pumps	USD	
Conveyors and conveying equipment	USD	
Industrial trucks and tractors	USD	
Pipe, valves, and pipe fittings	USD	
Plumbing fixture fittings and trim	USD	
Turbines and turbine generator sets	USD	
Motors and generators	USD	
Water supply and sewerage systems	USD	
Material		
Reinforcing steel, at plant/RER U	kg	108,883
Concrete, normal, at plant/CH U	m3	753
Concrete (reinforced) I	kg	
Brick, at plant/RER U	kg	
Wood board ETH U	kg	
Sand ETH U	kg	
Hard coal mix, at regional storage/UCTE U	kg	
Gravel ETH U	kg	
HDPE pipes E	kg	
PVC pipe E	kg	2,059
Glass fibre reinforced plastic, polyamide, injection moulding, at plant/RER U	kg	
Glass fibre reinforced plastic, polyester resin, hand lay-up, at plant/RER U	kg	
Polyethylene, HDPE, granulate, at plant/RER U	kg	
St13 I - Material	kg	
Copper I - Material	kg	
Copper product manufacturing, average metal working/RER U	kg	
Aluminium, production mix, at plant/RER U - Material	kg	
Aluminium product manufacturing, average metal working/RER U - Processing	kg	
Chemical		

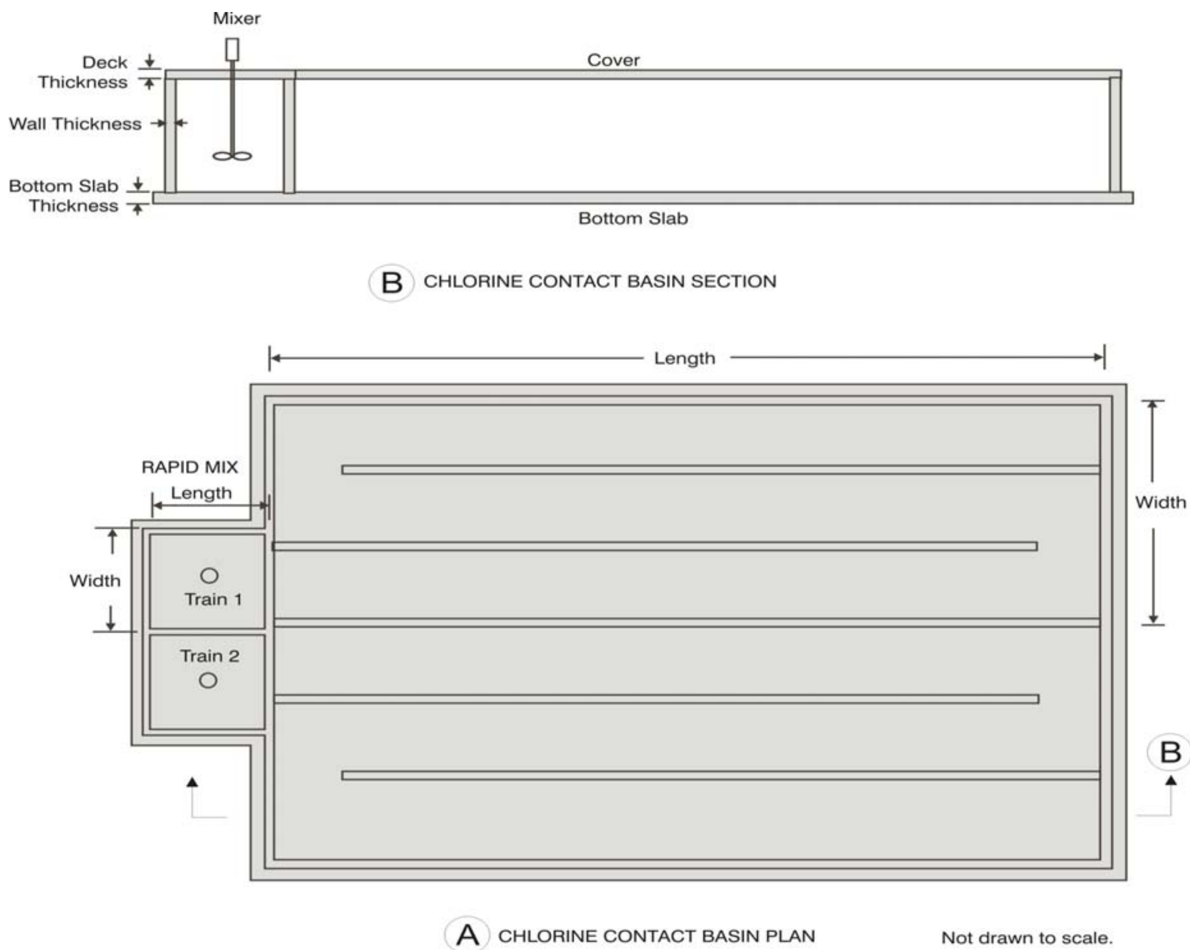
Module 8
Chlorine Contact Basin

Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	kg	
Sodium hypochlorite, 15% in H2O, at plant/RER U	kg	
Lime, hydrated, packed, at plant/CH U	kg	
Quicklime, milled, packed, at plant/CH U	kg	
Sulphuric acid, liquid, at plant/RER U	kg	
Aluminium sulphate, powder, at plant/RER U	kg	
Iron (III) chloride, 40% in H2O, at plant/CH U	kg	
Hydrochloric acid, from the reaction of hydrogen with chlorine, at plant/RER U	kg	
Hydrochloric acid, 30% in H2O, at plant/RER U	kg	
Phosphoric acid, industrial grade, 85% in H2O, at plant/RER U	kg	
Ammonium sulphate, as N, at regional storehouse/RER U	kg	
Energy		
Electricity, high voltage, at grid/US U (Life Cycle)	kWh	813,596
Natural gas, at consumer/RNA U	MJ	

Notes and Disclaimers:

1. This represents a conceptual level analysis. No structural details such as special foundation requirements, piping penetrations, overflow, perforated walls, gates and valves were considered. Assume single wall thickness, slab thickness and deck thickness. This could be detailed in future phase of research.
2. No site specific civil site work was included in this analysis. No power supply infrastructure is included. No control and instruments were included.
3. The equipment costs included herein are based on generic equipment used for similar facility. Prices were not verified in this phase and should be further developed in future phases.
4. No residuals handling facility was included in the study boundary.

Module 8
Chlorine Contact Basin



Appendix B

FUTURE RESEARCH PLAN

Science and Technology Research Proposal and Performance Contract Management (PropC) System

Proposal Preparation Information Template

I. GENERAL INFORMATION

I.A. Title:

Full Scale Plan of Research Outline: Quantifying Embedded Water/Energy In a Water Treatment System

I.B. State the question your R&D would answer:

This is your research hypothesis. State it carefully to provide key insight into the primary question your proposal is intended to answer as it relates to and benefits Reclamation's mission of managing and delivering water and power. **Maximum number of characters:** 1,000

In many water scarce regions, like the southwest, communities are considering using lower quality water resources and more energy intensive treatment processes to supply their potable water needs. Utilities need help in comparing water supply and treatment options (e.g., membranes (RO/NF, MF/UF), advanced oxidation process (UV and ozone)) while considering environmental impacts, including the water and energy impacts. Utilities also need help in determining if and how renewable energy may offset these energy intensive processes. This Plan of Research will analyze data to reduce the environmental impacts of impaired water treatment and translate it into meaningful water system efficiencies.

The primary objective of this research is to assess the environmental impacts in a water treatment system and provide efficiency alternatives for improved water management. The method of collection and analysis of data will be through the use of life cycle assessment tools to simplify data manipulation.

Another objective is to assess the impact of the use of renewable energy on the embedded water and energy in the water treatment system. This could help support Reclamation's renewable energy initiatives and provide bases for establishing energy rated policies and prioritize renewable energy projects.

I.C. R&D Focus and R&D Output Area:

Improving Water Operations Decision Support, DS3 Water Operation Models and Decision Support Systems

I.D. Proposed Start and Completion Years:

2013 - 2014

I.E. Type of Proposal:

Conducting research and development

I.F. Security and Intellectual Property Information:

No

II. PROPOSED R&D END PRODUCTS AND COMPLETION DATES

II.A. Enter the end products of your R&D proposal:

- A method and data to quantitatively assess environmental impacts (particularly embedded water and energy) of different water treatment systems (e.g., membranes (RO/NF, MF/UF), UV and ozone).
- Case studies that demonstrate how the method and data helped utilities examine the environmental impacts of their actual or potential water supply and treatment processes.
- A report explaining how utilities can use the method and the data and perform a self-assessment on treatment system sustainability.

II.B. Need and Benefit:

Describe existing capabilities available to Reclamation from both internal and external sources. Explain why they are insufficient to adequately serve Reclamation's needs. **Maximum number of characters:** 4,000

Paradoxically, water is our most precious, most wasted, and most undervalued resource. Producing and delivering water from sources with various water qualities consumes commercial products such as energy, equipment, instruments, and chemicals, each of which contains embedded water or removes locally available water from consideration for other uses. The life cycle assessment helps to raise the awareness of the true value of water by accounting for the embedded volume of freshwater, energy and natural resources used to produce the centrally distributed water as a product measured over the full supply chain. Applying the life cycle impact assessment concept in real world situations, such as comparing lower water quality sources and treatment, will illustrate how this concept will help utilities consider the full spectrum of impacts.

In many water scarce regions, like the southwest, communities are considering using lower quality water resources and more energy intensive treatment processes to supply their potable water needs. Utilities need help in comparing water supply and advanced treatment options (e.g., membranes and advanced oxidation processes) while considering environmental impacts, including the water and energy impacts. Utilities also need help in determining if and how renewable energy may offset these energy intensive processes.

Life cycle assessment (LCA) as an ISO formalized method for assessing the environmental aspects and potential impacts associated with a product or system has been around for 20 years. Research studies using LCA technique to evaluate environmental impacts of water/wastewater systems started to develop in the past decade. However, information customized for water utilities in their implement to evaluate water sources and treatment technology options regarding environmental sustainability consideration is scarcely available. A user-customizable tool that can help water utilities to evaluate a full process train (from water supply to distribution) is not readily available for implementation. Although some research studies, as briefly exampled below, focused on comparing individual water/wastewater treatment technologies, water supply, and energy options using LCA method, blank spot of data gap and systematic tool development are still pending further study, particularly for water scarce areas like the southwest US.

- Bonton, et al (2012) conducted a comparative life cycle assessment of two water treatment plants (a conceptual conventional-GAC plant vs. an actual nanofiltration plant existing in Canada) using SimaPro software. The conclusion revealed that operation phase has the highest potential environmental damage, and conventional-GAC system has greater environmental impacts than a nanofiltration system, based on the local dominant hydroelectricity power supply. Although effectively presented the use of LCA technology in water system life cycle assessment, this study did not provide available information for utility self assessment.

- Vince, et al (2008) conducted LCA on potable water production processes, focusing on desalination alternatives, based on European drinking water standards. This study drew conclusion that electricity production for plant operation is the main source of environmental impacts, followed by chemical production for coagulation and remineralization. The study showed that advanced membrane desalination has higher chemical and energy consumption than conventional groundwater/surface water treatment processes.

- Dr. Jennifer Stokes and Prof. Arpad Horvath at University of Berkeley conducted large amount of work on Water-Energy Sustainability Tool (WEST). The initial tool release took place in December 2010. Over years, this tool has been under further development and refine. With the similar intention as the proposed research, the WEST allows user input of treatment processes, materials and quantities to build LCA inventory. The WEST development focuses mostly in California scenarios to meet local water scarcity and available water sources. The proposed study will focus on the southwest water environment conditions and local stakeholders' interest, and provide a practical module input, user-friendly tool for local utilities' convenience to employ.

- Regarding energy LCA, the Water Environment Research Foundation (WERF) researchers started the development of Green Energy Life Cycle Assessment Tool (GELCAT) in 2009, for wastewater utilities implementations. This Microsoft Excel-based screening tool aims to assess green energy options (e.g., solar or winder power generation) life cycle environmental impact and help utilities to use green energy at facilities in North America. Water Research Foundation (WaterRF) is currently working on potential partnership to expand the research by adding drinking water perspective in the tool development.

Collecting credible raw data and assembling easily usable modules is the key to accurately and efficiently conduct full water footprint assessment and LCA for water utilities and water-related business. The current LCI database includes very few commonly used water conveyance and treatment components. For example:

- Among its over 4,000 datasets in Ecoinvent, one dataset for pumps and one for compressors is all that are directly relevant to the water conveyance and treatment equipment. These datasets are expressed generically in U.S. dollars, without differentiating the types (e.g., a centrifugal pump versus a progressing cavity pump), the size (hundreds of million gallons a day versus a few of liters an hour), and the materials used for construction.

- The currently available LCI database includes hundreds of data entries for chemical industry, but has little information about typical water treatment chemicals such as polymer, antiscalant, or powder activated carbon.
- The databases provide quite a lot of information on building construction materials such as concrete, metals, wood, and plastics, but have limited information regarding the manufacturing process of metal or plastic pipes.
- No existing database includes materials (e.g., polyvinylidene fluoride (PVDF), polyamide, and polysulfone) and processes (e.g., membrane casting, rolling, and assembling) commonly used for making ultrafiltration and RO membranes.
- Water utilities need a comprehensive, consistent, and critically reviewed inventory database that is customized to cover the most commonly used water conveyance and treatment equipment (e.g., pumps, valves, blowers, membrane elements), materials (e.g., water treatment chemicals, aluminum covers, fiberglass reinforced plastic duct, GAC), and processes (e.g., membrane production, GAC regeneration, filter backwash).

Working with water utility and industry partners (on selected case studies), the proposed research will demonstrate the benefits to integrate/incorporate the embedded water and energy concept when it comes to sustainability evaluation for water resources planning, water conveyance, and water treatment. This will benefits Reclamation and water providers in optimizing water system efficiency, promoting water and energy conservation and innovative sustainable technologies in water conveyance, treatment and operation, and supporting informed decision making on natural resource allocation and planning.

Renewable energy is a priority area for Reclamation research. Better understanding of the environmental impacts associated with water treatment facilities powered on grids receiving conventional power (e.g., coal, gas, oil), versus alternative power (hydro, solar, wind, biofuel, etc.) will help Reclamation to prioritize renewable energy projects and improve energy policies. It will also help water utilities to improve their renewable energy planning efforts and improve the sustainability of water production.

II.C. Why is this the responsibility of Reclamation and not another government agency or the private sector?

Maximum number of characters: 3,000

Reclamation's mission involves managing water in an economically efficient and environmentally sensitive manner. Mission requirements often involve conducting research and studies before introducing new concepts that could lead to useful modifications and strategies in water management and policy. The Colorado River serves approximately 30 million people in the United States and Mexico. Reclamation manages the River and its reservoirs to meet water delivery obligations, provide flood control, generate hydropower, protect endangered species and native habitat, and enhance outdoor recreation opportunities.

Over decades, the Phoenix Area Office has been involved at the local level, in water management and development of sustainable water supplies in Arizona. It is critical to integrate the Renewable Energy Initiative, a priority area in Reclamation research, through practical application in ongoing work. Working with water utility and industry partners, the proposed research will demonstrate how it is beneficial to include the embedded water and energy concept when evaluating alternatives in water resources planning, water conveyance, and water treatment. This project will present sensitivity analyses on environmental impacts associated with water treatment facilities powered on grids receiving conventional power (e.g., coal, gas, oil), versus alternative power (hydro, solar, wind, biofuel, etc.). It is critical for Reclamation to establish and improve methodologies and collect critical data in assessing efficiency in water conveyance and its energy structure as justification of implementing renewable energy projects.

III. PROPOSED STEPS TO PRODUCE THE R&D END PRODUCTS LISTED IN SECTION II

III.A Methods and Approaches, End Product Dissemination:

Briefly describe the methods and approaches you will use to answer your research question and how you will share your research end product(s) with peers and stakeholders. **Maximum number of characters:** 4,000

The technical approach for the proposed study will consist of the following steps:

- Task 1: Expand the prototype LCA data collection. Determine the high priority data elements (and their numeric value)
- Task 2: Workshop- to get utility input on specific research ideas.
- Task 3: Water Utility Case Studies
- Task 4: Power Supply Sensitivity Analysis

The following briefly describes these steps.

Task 1: Expand the prototype LCA data collection

- Expand the prototype LCA data established in Phase 1 of the study. Fill in data gap using available literature references and published database information.
- Update literature review with up-to-date on-going research, applications, opportunities, and challenges related to LCA analysis in the field of water industry.
- Establish a data collection plan.
- Prioritize the data collection efforts.
- Collaborate with industry partners (e.g., equipment manufacturers or professional organizations) to collect raw data for water industry on membrane technologies and advanced oxidation processes.

Task 2: Stakeholder Workshop

- Conduct stakeholder workshop to prioritize the data wish list generated in Phase 1 study, focusing on the interest of the southwest region of the United States, i.e., Reclamation service area.
- Invite Reclamation and utilities who are using lesser water quality sources.
- Investigate the opportunities for Reclamation and Drinking Water Utilities to integrate the use of LCA analyses into sustainable planning and operations.
- Gather inputs form water utilities to prioritize the data collection and establish case study areas.

Task 3: Water Utility Case Studies

- Select case study topics gathered at the stakeholder workshop (described in Task 2).

- Identify case study partnership. Set case study boundaries.
- Potential case study # 1: Investigate embedded water and energy associated with three water supply alternatives for central Arizona, including imported water, brackish water desalination, and indirect potable reuse.
- Potential case study # 2: Wastewater Treatment Plant Reclaimed Water Appraisal Study, which evaluates the environmental impacts of using reclaimed water as for other purposes (such as power plant cooling water, wetland restoration, and indirect potable reuse)

Task 4: Power supply sensitivity analysis

- Review current status of renewable energies as power supply alternatives, such as wind, solar, or taking advantage of biogas for power cogeneration in situ.
- Collect renewable energies data based on literature review and available LCA software and database. Investigate opportunities to corporate with NREL and utilize their expertise and knowledge to assist the data collection.
- Conducted sensitivity analysis using LCA results to evaluate environmental impacts generated by various power supply sources.

III.B Proposed Steps to Produce the Research End Products:

List the sequential steps that you will take to conduct your R&D and share the results with end users and peers to promote adoption of your research end product. Required fields are marked with an asterisk (*).

Task 1

Step or Task *

Step or task to produce the research end products listed in Section II.A (400 character limit)

Expand the prototype LCA data

Requested S&T Budget *	Enter whole dollars without commas or decimals $100,000
Scheduled Complete Date *	mm/dd/yyyy 6/30/2014

Task 2

Step or Task *

Step or task to produce the research end products listed in Section II.A (400 character limit)

Workshop – get utility input

Requested S&T Budget *	Enter whole dollars without commas or decimals $50,000
Scheduled Complete Date *	mm/dd/yyyy 6/30/2014

Task 3

Step or Task *

Step or task to produce the research end products listed in Section II.A (400 character limit)

Water Utility Case Studies

Requested S&T Budget *	Enter whole dollars without commas or decimals $100,000
Scheduled Complete Date *	mm/dd/yyyy 6/30/2014

Task 4

Step or Task *
Step or task to produce the research end products listed in Section II.A (400 character limit)

Power Supply Sensitivity Analysis

Requested S&T Budget *	Enter whole dollars without commas or decimals $150,000
Scheduled Complete Date *	mm/dd/yyyy 6/30/2014

IV. FISCAL YEAR S&T PROGRAM FUNDING REQUEST

2013 - 2014

V. PARTNERS – COST-SHARING WITH OTHERS WHO HAVE A STAKE IN THIS EFFORT

V.A Partners:

List the sequential steps that you will take to conduct your R&D and share the results with end users and peers to promote adoption of your research end product. Required fields are marked with an asterisk (*).

Partner 1

Partner First Name*	Charlie
Partner Last Name*	He

Organization*
For Reclamation organizations enter their mail code (PN-xxxx). For outside Reclamation, spell out the name of the organization (i.e. U.S. Fish & Wildlife Service, not FWS)

Carollo Engineers, Inc.

Telephone*	xxx-xx-xxxx 602-263-9500
Email*	che@carollo.com

Partnership Status*
Firm is defined as the leveraged funds or in-kind services directly associated with proposed research effort that is obligated or committed. Potential is defined as high likelihood of securing the funds or services indicated, but no commitment has yet been made. Provide other qualifying statements and considerations in the section X comments as appropriate.

Firm

Inside or Outside *	Outside of Reclamation

Partner 2

Partner First Name*	Maureen
Partner Last Name*	Hodgins

Organization*
For Reclamation organizations enter their mail code (PN-xxxx). For outside Reclamation, spell out the name of the organization (i.e. U.S. Fish & Wildlife Service, not FWS)

Water Research Foundation

Telephone*	xxx-xx-xxxx 303-734-3465

Email*	mhodgins@waterrf.org
Partnership Status* Firm is defined as the leveraged funds or in-kind services directly associated with proposed research effort that is obligated or committed. Potential is defined as high likelihood of securing the funds or services indicated, but no commitment has yet been made. Provide other qualifying statements and considerations in the section X comments as appropriate.	
Potential	
Inside or Outside *	Outside of Reclamation
Partner 3	
Partner First Name*	Darlene
Partner Last Name*	Tuel
Organization* For Reclamation organizations enter their mail code (PN-xxxx). For outside Reclamation, spell out the name of the organization (i.e. U.S. Fish & Wildlife Service, not FWS)	
Reclamation, Phoenix Area Office	
Telephone*	xxx-xx-xxxx 623-773-6268
Email*	DTuel@usbr.gov
Partnership Status* Firm is defined as the leveraged funds or in-kind services directly associated with proposed research effort that is obligated or committed. Potential is defined as high likelihood of securing the funds or services indicated, but no commitment has yet been made. Provide other qualifying statements and considerations in the section X comments as appropriate.	
Firm	
Inside or Outside *	Inside of Reclamation
V.B Partner Contribution Associate partner contributions with partners using the form below. Note that you must first add partners in Section V.A. before you can add their contributions. Required fields are marked with an asterisk (*).Add new partner contributions as needed using the template below.	
Partner Contribution 1	
Partner *	Carollo Engineers, Inc.
Contribution Description* 250-character limit	
Click here to enter text.	
Cash or In-Kind*	In-Kind
Fiscal Year*	2013 - 2014
Projected Contribution*	Enter whole dollars without commas or decimals $
Partner Contribution 2	
Partner *	Water Research Foundation

Contribution Description* 250-character limit	
Click here to enter text.	
Cash or In-Kind*	Cash
Fiscal Year*	2013 - 2016
Projected Contribution*	Enter whole dollars without commas or decimals $Click here to enter text.
Partner Contribution 3	
Partner *	USBR
Contribution Description* 250-character limit	
Click here to enter text.	
Cash or In-Kind*	Cash
Fiscal Year*	2013 - 2016
Projected Contribution*	Enter whole dollars without commas or decimals $Click here to enter text.

VI. ADVOCATES

This section is optional. Add information about a new advocates as needed using the template below. Required fields are marked with an asterisk (*).

Advocate 1	
First Name*	Darlene
Last Name*	Tuel
Title*	Water Resource Planner
Organization* For a Bureau of Reclamation organization, enter the mail code (PN-xxxx). For outside Reclamation, spell out the name of the organization (i.e. U.S. Fish & Wildlife Service, not FWS)	
Click here to enter text.	

Telephone*	xxx-xx-xxxx 623-773-6268
Email*	dtuel@usbr.gov
Advocate 2	
First Name*	Click here to enter text.
Last Name*	Click here to enter text.
Title*	Click here to enter text.
Organization* For a Bureau of Reclamation organization, enter the mail code (PN-xxxx). For outside Reclamation, spell out the name of the organization (i.e. U.S. Fish & Wildlife Service, not FWS)	
Click here to enter text.	
Telephone*	xxx-xx-xxxx Click here to enter text.
Email*	Click here to enter text.
Advocate 3	
First Name*	Click here to enter text.
Last Name*	Click here to enter text.
Title*	Click here to enter text.
Organization* For a Bureau of Reclamation organization, enter the mail code (PN-xxxx). For outside Reclamation, spell out the name of the organization (i.e. U.S. Fish & Wildlife Service, not FWS)	
Click here to enter text.	
Telephone*	xxx-xx-xxxx Click here to enter text.
Email*	Click here to enter text.

VII. RESEARCH BENEFICIARIES AND R&D LOCATIONS

VII.A Primary Research Beneficiaries:

Reclamation, water utilities

VII.B R&D Location:

Phoenix, AZ

VII.C NEPA Compliance

Click here to enter text.

VIII. PROJECT TEAM

Add information about a new project team member as needed using the template below. Required fields are marked with an asterisk (*).

Project Team Member 1

First Name*	Charlie
Last Name*	He
Discipline or Specialty*	
Civil Engineer, Salinity Management, Process Optimization	
Organization* For Reclamation organizations enter their mail code (PN-xxxx). For outside Reclamation, spell out the name of the organization (i.e. U.S. Fish & Wildlife Service, not FWS)	
Carollo Engineers, Inc.	
Telephone*	xxx-xx-xxxx 602-263-9500
Email*	che@carollo.com
Principle Investigator?*	Yes

Project Team Member 2

First Name*	Zhuang
Last Name*	Liu
Discipline or Specialty*	
Civil Engineer, Infrastructure and Planning	
Organization* For Reclamation organizations enter their mail code (PN-xxxx). For outside Reclamation, spell out the name of the organization (i.e. U.S. Fish & Wildlife Service, not FWS)	
Carollo Engineers, Inc.	
Telephone*	xxx-xx-xxxx 602-263-9500
Email*	zliu@carollo.com
Principle Investigator?*	No

Project Team Member 3

First Name*	Guy
Last Name*	Carpenter
Discipline or Specialty*	
Civil Engineer, Water Reuse and Resources Management	

Organization* For Reclamation organizations enter their mail code (PN-xxxx). For outside Reclamation, spell out the name of the organization (i.e. U.S. Fish & Wildlife Service, not FWS)	
Carollo Engineers, Inc.	
Telephone*	xxx-xx-xxxx 602-263-9500
Email*	gcarpenter@carollo.com
Principle Investigator?*	No
Project Team Member 4	
First Name*	Ke
Last Name*	Li
Discipline or Specialty*	
Life Cycle Assessment, Embedded Water and Energy Accounting	
Organization* For Reclamation organizations enter their mail code (PN-xxxx). For outside Reclamation, spell out the name of the organization (i.e. U.S. Fish & Wildlife Service, not FWS)	
University of Georgia	
Telephone*	xxx-xx-xxxx Click here to enter text.
Email*	Click here to enter text.
Principle Investigator?*	No

IX. POTENTIAL TECHNICAL REVIEWERS

Enter the names and contact information for three technical reviewers outside of Reclamation that are qualified to review your research proposal.

Technical Reviewer 1 and Advisor	
First Name*	Leslie
Last Name*	Meyers
Title*	Chief, Program Development Division, P.E.
Organization* Spell out the name of the organization (i.e. U.S. Fish & Wildlife Service, not FWS)	**Reclamation**
Click here to enter text.	

Telephone*	xxx-xx-xxxx Click here to enter text.
Email*	Click here to enter text.
Technical Reviewer 2	
First Name*	Click here to enter text.
Last Name*	Click here to enter text.
Title*	Click here to enter text.
Organization* Spell out the name of the organization (i.e. U.S. Fish & Wildlife Service, not FWS)	
Click here to enter text.	
Telephone*	xxx-xx-xxxx Click here to enter text.
Email*	Click here to enter text.
Technical Reviewer 3	
First Name*	Click here to enter text.
Last Name*	Click here to enter text.
Title*	Click here to enter text.
Organization* Spell out the name of the organization (i.e. U.S. Fish & Wildlife Service, not FWS)	
Click here to enter text.	
Telephone*	xxx-xx-xxxx Click here to enter text.
Email*	Click here to enter text.

X. COMMENTS AND ADDITIONAL INFORMATION

Use this space to provide any additional information regarding this proposed effort. **Maximum number of characters:** 4,000

Click here to enter text.

XI. TEAM QUALIFICATIONS

This section is optional. **Maximum number of characters:** 4,000

Carollo Engineers is an environmental engineering firm specializing in the planning, design, and construction of water and wastewater facilities. Carollo's reputation is based upon client service and a continual commitment to quality. We currently maintain 32 offices in 12 states.

During our 78-year history, Carollo has successfully completed more than 20,000 projects for public sector clients. Carollo is currently ranked within ENR top 100 design firms. More importantly, *ENR's* annual Source Book ranks Carollo among the top 10 firms for water and wastewater treatment plant design.

Carollo has been a leader in the development of water and wastewater system hydraulic and optimization models and master plans for water agencies facing a variety of complex issues. We are experienced in creating comprehensive, effective and user-friendly computer simulation and optimization models of water and wastewater systems.

Carollo Engineers has long been a leader in engineering water reuse systems and desalination and concentrate management systems. We recognize the value of recycling, reuse and desalination to conserve finite resources, expand new sources and protect our environment. Our water reuse projects produce more than 40 billion gallons of reclaimed water each year, which is used to irrigate golf courses, parks and agricultural crops, and used for power plant cooling, groundwater replenishment, wetland maintenance and recreational purposes. Our in-house water research group maintains a lab for conducting research for new reuse technologies and treatment. We are dedicated to conserving this valuable resource and preserving our environment.

Carollo strongly supports sustainable design and energy conservation initiatives by excelling in the application of green building practices that incorporate LEED® design features in its water, wastewater, water resources, and infrastructure projects nationwide. Many employees throughout the company are LEED® Accredited Professionals and several engineers are in the process of applying for LEED® accreditation. Carollo has assisted our clients to incorporate LEED® design principles and to meet various levels of LEED® rating.

Carollo is a recognized leader in its ability to integrate innovative technology with sustainable design principles. Our science-based approach to process design results in more finely tuned projects that “do more with less.” Carollo typically incorporates many elements of energy efficient/sustainable design into our projects, resulting in lower life-cycle energy consumption.

About Team Members

Mr. Charlie (Qun) He, an associate and environmental senior project engineer with Carollo, has more than ten years of experience in water and wastewater treatment, water quality data analysis, computer modeling, advanced analytical work, environmental chemistry, water resource, hydrology, water distribution, and wastewater collection and treatment. Mr. He obtained experience in membrane technologies, including MBR, brackish water Reverse Osmosis (RO), seawater RO, and membrane concentrate management studies, testing and design. He became the company’s membrane desalination and concentrate management expert for the southwest region. He is the southwest regional lead of the Carollo's Research Group.

Mr. He has gained extensive experience in water and wastewater treatment, conventional and advanced digestion process and advanced wastewater treatment. He is skilled at mathematical modeling such as BioWin, Biotran, the EPA WTP model, and both empirical and mechanistic based DBP prediction modeling. He is a member of the company's wastewater process technology group and the advanced digestion group.

Dr. Zhuang Liu has over 9 years of experience specializing in water and wastewater treatment processes studies and design, groundwater treatment and contamination control, and hydrologic and hydraulic modeling. She was the project engineer for Water Research Foundation tailored collaboration project Lowering Chemical and Energy Usage for Inland Desalination Concentrate Volume Reduction. Zhuang developed the life cycle assessment model to evaluate the true environmental impacts of various desalination and concentrate management technologies.

Mr. Guy Carpenter, a vice president with Carollo, has over 20 years of experience in water, water resources, wastewater, and reclaimed water consulting and master planning. His experience includes operations, capital project budgeting and management, decision support, management consulting, system evaluations, water resource development support, water rights negotiations and valuations, water resource accounting and management, and permitting. Guy is a water resources leader, able to help clients determine how to legally and physically develop and deploy water resources in a safe, reliable, and economic manner.

Dr. Ke Li, an Assistant Professor at the University of Georgia. Li has studied the life-cycle environmental impacts of urban design and construction. He conducted various alternative evaluation and decision support studies for sustainable infrastructure and urban growth.