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User Manual

for the Pacific Institute Water to Air Models

*Prepared by Gary Wolff, P.E., Ph.D., Principal Economist and Engineer
with Sanjay Gaur, Model Engineer
and Maggie Winslow, Ph.D., Air Quality Specialist*

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Editor: Nicholas Cain

Designer: Bryan Kring, Gas Tank Graphix

Pacific Institute for Studies in Development, Environment, and Security

654 13th Street, Preservation Park

Oakland, California 94612

www.pacinst.org

telephone 510-251-1600

telefax 510-251-2203

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PREFACE

The Pacific Institute Water to Air Models allow water managers to quantify the energy and air quality impacts of their management decisions. These impacts are increasingly relevant to water decision-making, as energy-intensive options like seawater desalination and inter-basin transfers are weighed against less energy-intensive options such as conservation, use-efficiency, conjunctive use, or reclaimed wastewater. The urban and agricultural models documented in this manual provide a flexible but consistent framework for quantifying the energy and air quality dimensions of water management decisions. They advance our analytical capacities in a fully transparent way and support rational discussion and more detailed analysis of the economically and environmentally important water/energy/air quality “nexus”.

The models permit users to specify the facilities in their water system from sources through consumptive use or disposal. For each facility the user specifies its annual water throughput, the amount of energy used at that facility, and the sources of energy for that facility. This can be done for two scenarios at a time. The model then computes energy use, energy intensity, and air emissions for each scenario, and the difference between scenarios.

Why Were These Models Created?

The Pacific Institute (PI) recently worked with the Natural Resources Defense Council (NRDC) to evaluate the energy used in water management (Wolff, et.al., 2004) based on methods pioneered by Bob Wilkinson of the University of California, Santa Barbara (Wilkinson, 2000). The NRDC/PI report—which Bob Wilkinson served as an advisor on—includes case studies of San Diego County, the Westlands Water District in Central California, and the Columbia Basin Project in the Pacific Northwest. The report is available at no charge from www.pacinst.org/publications.

One of the conclusions of that work was that energy use in urban water management in California is even more significant than previously recognized, primarily because energy used during customer use of water (e.g., for heating water) is often at least as large as energy used to extract, transport, treat, distribute, collect, and dispose of water and wastewater properly. For example, the San Diego County case study found that the equivalent of about 7,000 kilowatt hours (Kwh) of electricity are used for each acre-foot of water used there, with more than half of that energy use taking place on the customer side of the water meter but prior to wastewater discharge. To put this in context, conserving 100,000 acre-feet of water per year would save enough energy to power 25% of residences in the City of San Diego for a year.

The work also found that the energy implications of land fallowing decisions (dry year or permanent) could be significant, depending on the final disposition of water no longer required to irrigate. If the water were left in the source ecosystem (e.g., in the Bay-Delta for the State Water Project or the US Central Valley Project), energy use could be much smaller than at present; if sent to distant urban areas, energy use could be much larger than at present. For example, fallowing 100,000 acres in the Westlands Water District could reduce electricity use by 71 million kwh per year, or increase it by 1,300 million (1.3 billion) kwh per year. Even when kept within the irrigation district that fallowed land, the energy implications of different water use patterns can be significant because having more water per acre of

land still cropped can change crop patterns, irrigation practices, and energy used to cultivate and harvest crops.

Given this, the air quality implications of water management decisions may be significant, since energy production and use is often a substantial source of air pollutants. Environmental Impact Reports (EIRs) prepared under the California Environmental Quality Act (CEQA) and Environmental Impact Statements (EISs) prepared under the US National Environmental Policy Act (NEPA) rarely contain a thorough (or any) evaluation of the potential air pollution impacts of energy used in water projects. For example, the Environmental Impact Report/Environmental Impact Statement (EIR/EIS) for the water transfer from the Imperial Irrigation District to the San Diego County Water Authority did not discuss these impacts even though about 300 million (2,110 kwh per acre-foot times 143,000 acre-foot per year, average) kwh of electric consumption or foregone hydroelectric production will be involved each year.

Consequently, the Institute decided to prepare two spreadsheet models usable by water managers to assess both the energy and air pollutant emissions that might result from their water management decisions. One is for urban water managers; the other is for managers of agricultural irrigation water.

How Can the Models Help Me?

Both models allow comparison of the energy use and air pollutant emissions of two water management scenarios. The output sheet within the model shows estimated annual energy use and emissions for both scenarios, and the annual differences between the scenarios (Scenario Two minus Scenario One). Users create scenarios as described later in this manual.

The model outputs may be suitable for inclusion in environmental assessments: for example, program and project level EIRs and EISs. They are probably better suited for evaluation of programmatic alternatives than for evaluation of detailed project proposals and their alternatives. The key determinant of suitability for air quality emissions estimates is whether the

emissions factors in the model fairly represent the specific situation being modeled. We've designed the models to be as transparent as possible. All calculations, for example, take place in the spreadsheet marked "engine"; and assumptions are shown in the spreadsheet marked "assumptions." Everything in the model is visible to the viewer, although most cells have been locked to prevent accidental changes that would corrupt the output. (The default energy use values in the "Start" and "Facility" spreadsheets are not locked because doing so would interfere with the visual basic code.)

If the models are used in EIRs or EISs, they can be included in their entirety as appendices so that reviewers can critique the assumptions and methods used. Therefore, at minimum, the models provide a useful and uniform starting point for analysis of the air quality impacts of water management decisions.

It is also important to recognize what the models do not do. They do not evaluate marginal energy use or air emissions. All energy use and air emissions factors represent averages, not changes at the margin. For example, natural gas emissions are from average existing natural gas power plants. The models would probably overstate air emissions from new water facilities that rely on new natural gas power plants. The models also do not evaluate the impacts of air emissions. The health or environmental impacts of emissions may depend on where they occur. Finally, the models do not evaluate the indirect energy and air emissions differences between scenarios. For example, nuclear power plants are assumed to have zero air emissions, which is correct for their direct emissions. But construction of nuclear plants, like all construction, involves energy use and emissions. Indirect energy use and emissions are those embedded in the capital facilities themselves. Readers interested in indirect energy use and emissions in the water sector should look at the work of Horvath (2004), funded in part by the California Energy Commission.

Where Do I Get the Models?

The models are being provided free of charge by the Institute under a grant from the California Energy Commission Public Interest Energy Research (PIER)

Program. They can be downloaded from www.pacinst.org/resources/water_to_air_models. They run in Excel Versions 2002 and 2000. The models documented in this manual are labeled Version 1. If other versions are subsequently made available, an updated user manual will be provided at that time.

What Are the Model Inputs and Outputs?

Before trying to run the models it may be helpful for users to understand and see examples of typical model inputs and outputs. We provide two examples—one urban and one agricultural—below. ***You can also skip the examples and go directly to the section titled “How to Use the Models” that follows the examples.***

Both models require users to list the “facilities” at which energy is used in their water supply-use-disposal chain. For example, potable water treatment plants, distribution booster stations, types of end uses (e.g., clothes washing), and wastewater treatment plants are facilities. Facilities outside a water manager’s jurisdiction might be aggregated together into a single facility in the model. For example, water delivered by the State Water Project to a user located in Southern California will often be listed as a single facility labeled “State Water Project” within the “Imported Water” input spreadsheet.

Both models require users to list the amount of water that flows through each facility in acre-feet per year.

Both models allow users to specify the amount of energy used at each facility in total over a year, or to use a default energy factor per acre-foot in some cases. Default values are not always available, but are provided for the most common types of facilities so that users can experiment with the model even if they have little site-specific information. Users be warned: default values may be inaccurate in your setting. Data sources for default values used in the models, and other relevant information that might help users estimate their energy use at facilities, are provided in Appendix A.

Both models also require users to specify a mix of energy for every facility. A mix can be, for example,

100% electricity from the California Grid. Or it could be 50% from the Grid and 50% from hydroelectric plants. Up to nine sources of energy can be combined to make a mix, and the model allows users to specify as many as eight mixes. If users know their electricity comes from a particular utility, they can contact the utility and find out the percentages to use (e.g., of natural gas, coal, and nuclear) to create a local grid mix. Energy sources in the model also include some non-electric options like direct drive diesel pumps, which are widely used in agriculture.

The mix to use if you know nothing about your energy sources is 100% California Grid. This is average electricity purchased from the average electric utility in California.

Air pollution emissions factors are embedded in the models for each of the nine types of energy sources. Appendix B describes the data sources for the emissions factors. The models do not allow emissions factors to be changed at present. Again, users beware: model outputs may not be accurate for your particular circumstances. Nonetheless, the models provide at least a sense of the relative magnitude of potential energy and air quality impacts.

The model estimates average annual energy use and emissions for two scenarios created by the user, and also calculates the differences in energy use and emissions between the two scenarios. By running the model a number of times, users can evaluate and compare as many scenarios as they please.

Diagram 1 Start Tab for a San Diego Scenario One

PACIFIC INSTITUTE
Water to Air Model
Urban Management Version
 Designed by Gary Wolf
 Engineered by Sanjay Gaur

	California Grid Mix	Natural Gas Power Plant	Oil Fired Power Plant	Natural Gas Direct Drive	Coal Fired Power Plant	Hydro/ Solar /Wind /Nuclear	Diesel Direct Drive	Biogas Generation	Biogas Direct Drive
Mix 1	100%	0%	0%	0%	0%	0%	0%	0%	0%
Mix 2	0%	100%	0%	0%	0%	0%	0%	0%	0%
Mix 3	0%	0%	100%	0%	0%	0%	0%	0%	0%
Mix 4	0%	0%	0%	100%	0%	0%	0%	0%	0%
Mix 5	0%	0%	0%	0%	100%	0%	0%	0%	0%
Mix 6	0%	0%	0%	0%	0%	100%	0%	0%	0%
Mix 7	0%	0%	0%	0%	0%	0%	100%	0%	0%
Mix 8	0%	0%	0%	0%	0%	0%	0%	100%	0%

	Input > 1 Facility?	See Facility List	AF per Year	Use Default Values?	Default Energy Use (Kwh/Yr)	Actual Energy Use (Kwh/Yr)	Portfolio of Energy Mix
Sources and Conveyance			685000				
Groundwater	<input type="checkbox"/> Yes		30000	yes	19500000		Mix 1
Local Surface Water	<input type="checkbox"/> Yes		86000	No		6880000	Mix 1
Reclamation	<input type="checkbox"/> Yes		19000	yes	6650000		Mix 1
Imported	<input checked="" type="checkbox"/> Yes		550000				
Desalination	<input type="checkbox"/> Yes		0	No		0	Mix 1
Water Treatment	<input type="checkbox"/> Yes		685000	yes	37675000		Mix 1
Water Distribution	<input type="checkbox"/> Yes		651000	yes	257145000		Mix 1
Customer Use	<input type="checkbox"/> Yes		606000	no		2363400000	Mix 1
Waste Water Collection	<input type="checkbox"/> Yes		281000	yes	0		Mix 1
Waste Water Treatment	<input type="checkbox"/> Yes		281000	yes	123640000		Mix 1

Select Scenario: Scenario 1 Update Scenario

CALCULATOR - MGD to AF/YR or AF/YR to MGD			
Input	MGD	Output	AF/YR
0		-	

CALCULATOR - Liquid Energy to Equivalent kwh			
Fuel Type	Natural Gas	Output	equivalent kwh
0	100 cubic ft	-	

SAMPLE MODEL RUN: URBAN

Diagrams 1 and 2 show inputs for a possible Scenario One for San Diego County. The Scenario we've presented is an estimate for the service area of the San Diego County Water Authority (SDCWA) in

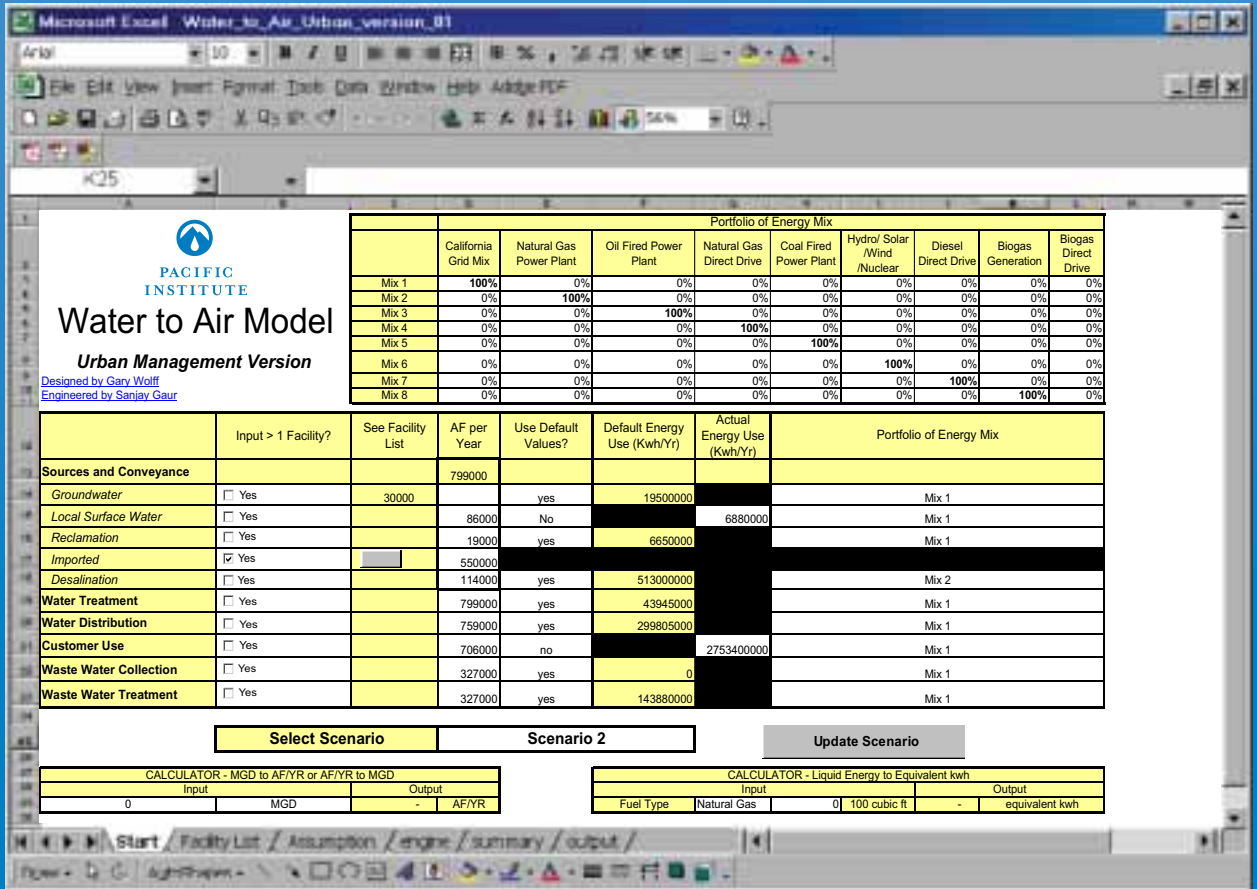
2003, assuming energy to run the Colorado River Aqueduct is 100% hydroelectric, and all other energy comes from the California Grid.

Diagram 2 Imported Water Facility Spreadsheet for a San Diego Scenario One

Portfolio of Energy Mix									
	California Grid Mix	Natural Gas Power Plant	Oil Fired Power Plant	Natural Gas Direct Drive	Coal Fired Power Plant	Hydro/ Solar /Wind /Nuclear	Diesel Direct Drive	Biogas Generation	Biogas Direct Drive
Mix 1	100%	0%	0%	0%	0%	0%	0%	0%	0%
Mix 2	0%	100%	0%	0%	0%	0%	0%	0%	0%
Mix 3	0%	0%	100%	0%	0%	0%	0%	0%	0%
Mix 4	0%	0%	0%	100%	0%	0%	0%	0%	0%
Mix 5	0%	0%	0%	0%	100%	0%	0%	0%	0%
Mix 6	0%	0%	0%	0%	0%	100%	0%	0%	0%
Mix 7	0%	0%	0%	0%	0%	0%	100%	0%	0%
Mix 8	0%	0%	0%	0%	0%	0%	0%	100%	0%

Return to Start

13			no						mix 1
14			no						mix 1
15			no						mix 1
16			no						mix 1
17	State Water Project	82000	no		265352000				mix 1
18	Colorado River Aqueduct	468000	no		936000000				Mix 6
19			no						mix 1
20	Others	0	yes	0					mix 1



We then created a Scenario Two that differed from Scenario One in only two ways. First, it provides an additional 100,000 acre-feet of water per year *to consumers* from seawater desalination plants.¹ Second, we specified average natural gas as the source of energy for these seawater desalination plants, rather than the California Grid. This illustration

DOES NOT represent a real choice being considered by the SDCWA. It is interesting, however, since seawater desalination is being explored in several Southern California jurisdictions, and because at least some of the possible facilities might be co-located with natural gas-generating facilities. Only one input screen differs between these scenarios (Diagram 3).

¹ Note that an additional 100,000 af/yr delivered to customers requires 114,000 af/yr of water produced at the seawater desalination plant. This is because 7% water is believed to be lost in distribution in San Diego County (100,000/0.93 = 108,000), and another 5% is believed to be lost in the treatment plants (108,000/0.95 = 114,000). Also, the quantity of wastewater to be collected increases by only 46,000 af since 54% of water delivered to customers in San Diego County is believed to be used consumptively. These types of water losses will be implicit in the model inputs users choose. For example, inputting a total for treatment of 108,000 af/yr while inputting 100,000 af/yr for the total of water distributed implies a loss in distribution of 7%.

Diagram 4A Urban Model Output Tab, Lower Third, Left Half

Difference Between Scenarios (Non-Zero Values will only appear)	AF per Year	Grams/ Year						
		Total organic gases	Reactive organic gases	Carbon monoxide	Nitrogen oxides	Sulfur oxides	Total particulates	Particulates < 10 microns
Sources & Conveyance	114,000	75,200,670	14,918,040	160,553,610	161,820,720	4,991,490	20,242,980	19,134,900
Groundwater								
Surface Water								
Reclamation								
Imported								
Desalination	114,000	75,200,670	14,918,040	160,553,610	161,820,720	4,991,490	20,242,980	19,134,900
Water Treatment	114,000	384,665	92,294	1,323,284	646,249	61,571	135,244	113,863
Water Distribution	108,000	2,617,191	627,955	9,003,393	4,396,966	418,921	920,176	774,706
Customer Use	100,000	23,926,500	5,740,800	82,309,500	40,197,300	3,829,800	8,412,300	7,082,400
Waste Water Collection	46,000							
Waste Water Treatment	46,000	1,241,724	297,933	4,271,652	2,086,137	198,757	436,577	367,558
Total		103,370,750	21,677,022	257,461,439	209,147,372	9,500,539	30,147,277	27,473,427

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[Designed by Gary Wolff](#)

Diagrams 4A and 4B show the estimated increase in energy use and emissions from moving to Scenario Two from Scenario One. Diagram 4A shows the left half of the lower third of the output tab; Diagram 4B shows the right half of the lower third of the output tab. Since units for emissions are grams per year, the increases in emissions shown in Diagram 4A are large numbers. To see the scale of these emissions increases, consider that the South Coast Air Quality Management District imposes fees on emissions of

nitrogen oxides, sulfur oxides, and particulate matter in excess of four tons per year. The output in Diagram 4A shows emissions of these compounds far greater than four tons per year. Converting to pounds at 454 grams per pound, and to tons at 2000 pounds per ton, the model estimates that implementing Scenario Two would increase annual emissions of nitrogen oxides, sulfur oxides, and total particulates by about 230, 10, and 33 tons per year, respectively, in comparison with Scenario One.

Diagram 4B Urban Model Output Tab, Lower Third, Right Half

Carbon Dioxide	Energy Use (equivalent kwh/YR)	Energy Factors (equivalent kwh/af of Customer Use)	Actual Electricity Use (Kwh/YR)	California Grid Mix	Natural Gas Power Plant	Oil Fired Power Plant	Natural Gas Direct Drive	Coal Fired Power Plant	Hydro/ Solar Wind /Nuclear	Diesel Direct Drive	Biogas Generation	Biogas Direct Drive
284,202,000.000	513,000.000	433										
		(5)										
		(2)										
		(2)										
		(285)										
284,202,000.000	513,000.000	727	513,000.000	-1.0	1.0							
2,953,170.000	6,270.000	0	6,270.000									
20,092,860.000	42,660.000	0	42,660.000									
183,690,000.000	390,000.000		390,000.000									
9,533,040.000	20,240.000	(0)	20,240.000									
500,471,070.000	972,170.000	434	972,170.000									

Similarly, Diagram 4B shows a large increase in kwh per year, a little over 972 million. Note that the increase in energy use (equivalent kwh per year) and actual electricity use (kwh per year) shown in Diagram 4B are the same in this example. They would not be if one or more energy mixes included

direct drive pumps powered, for example, by natural gas, diesel, or biogas. We included these totals separately in the model output so that impacts on the electric grid can be evaluated separately from total energy impacts.

Diagram 5 Start Tab for a Westlands Water District Scenario One

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Water to Air Model
Agricultural Management Version
 Designed by Gary Wolff
 Engineered by Sanjay Gaur

Portfolio of Energy Mix										
	California Grid Mix	Natural Gas Power Plant	Oil-Fired Power Plant	Natural Gas Direct Drive	Coal Power Plant	Hydro/ Solar /Wind /Nuclear	Diesel Direct Drive	Biogas Generation	Gasoline Direct Drive	
Mix 1	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mix 2	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Mix 3	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Mix 4	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Mix 5	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
Mix 6	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%
Mix 7	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
Mix 8	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%

	Input > 1 Facility?	See Facility List	AF per Year	Use Default Values?	Default Energy Use (Kwh/Yr)	Actual Energy Use (Kwh/Yr)	Portfolio of Energy Mix	
Sources and Conveyance			0					
Groundwater	<input type="checkbox"/> Yes		200000	yes	130000000			Mix 1
Local Surface Water	<input type="checkbox"/> Yes		0	No		0		Mix 1
Reclamation	<input type="checkbox"/> Yes		0	No		0		Mix 1
Imported	<input type="checkbox"/> Yes		800000	yes	400000000			Mix 6
Tailwater Reuse	<input type="checkbox"/> Yes		0	No		0		Mix 1
Water Distribution (In The Irrigation District)	<input type="checkbox"/> Yes		1000000	No		0		Mix 1
Customer Use, On-Farm Irrigation Systems	<input type="checkbox"/> Yes		900000	No		0		Mix 1
Drainage Management	<input type="checkbox"/> Yes		300000	No		0		Mix 1
Cultivation and Harvest	<input checked="" type="checkbox"/> Yes				3231000	Diesel Gallons	0	Gasoline Gallons

Scenario 1

CALCULATOR - MGD to AF/YR or AF/YR to MGD			
Input		Output	
0	MGD	-	AF/YR

CALCULATOR - Liquid Energy to Equivalent kwh			
Input		Output	
Fuel Type	Natural Gas	0	100 cubic ft
		-	equivalent kwh

SAMPLE MODEL RUN: AGRICULTURAL

Diagrams 5 and 6 show inputs for a possible Scenario One for growing cotton on 100,000 acres in the Westlands Water District in Central California. The Scenario we've presented assumes energy to deliver water to Westlands via the Central Valley Project is 100% hydroelectric, groundwater pumps on farms

use electricity from the California Grid, and fuel for cultivation and harvest of Alcala Cotton is diesel fuel (see Table A-3 for the source of this data). We've also arbitrarily assumed that 10% of source water is lost during distribution within the irrigation district (e.g., percolation from distribution canals), and that 2/3 of

Diagram 6 Cultivation and Harvest Facility Spreadsheet for a Westlands Water District Scenario One

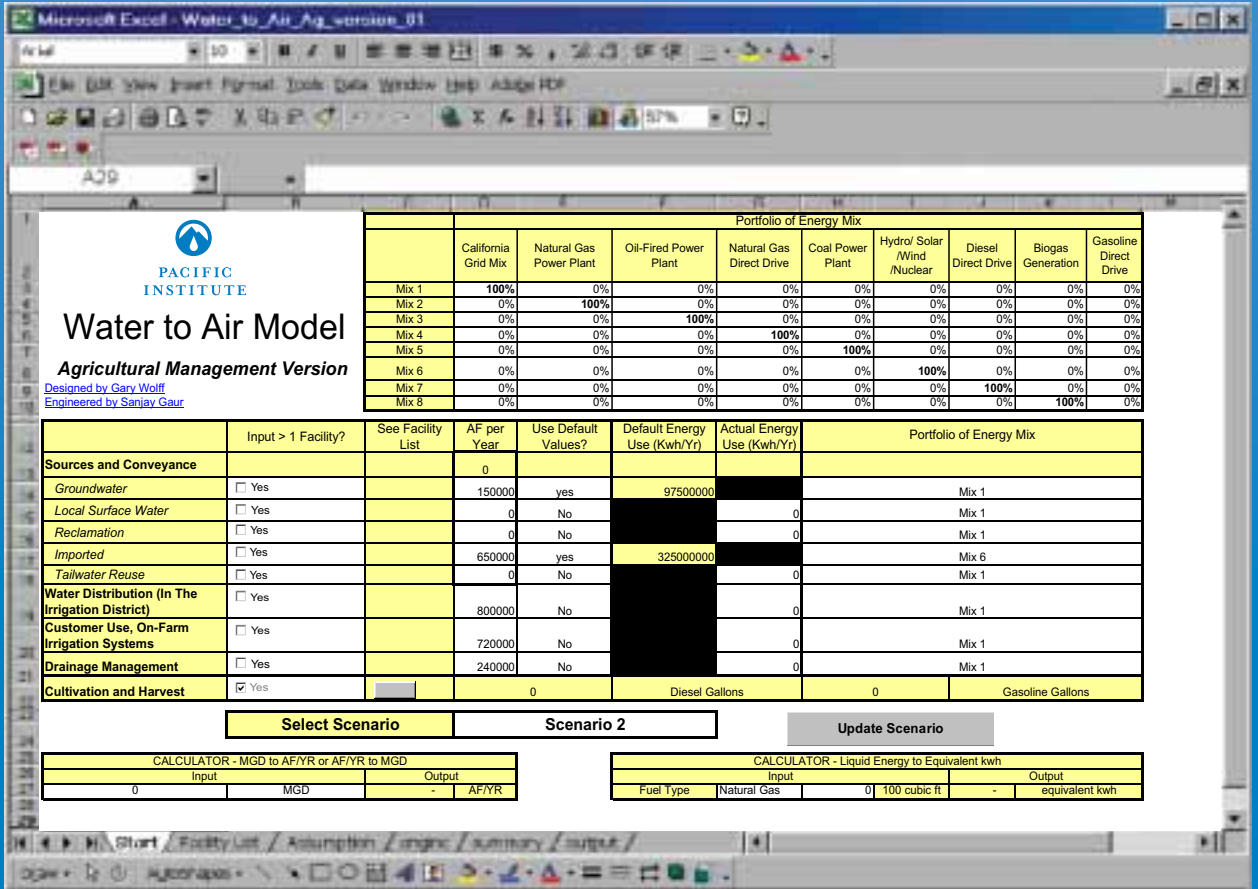
The screenshot shows a Microsoft Excel spreadsheet with two main sections. The first section is titled 'Portfolio of Energy Mix' and contains a table with 8 rows (Mix 1 to Mix 8) and 10 columns representing different energy sources. The second section is titled 'Cultivation and Harvest' and contains a table with 12 rows and 3 columns: 'Name of Cultivation and Harvest Activities', 'Diesel Gallons (annual use)', and 'Gasoline Gallons (annual use)'. The 'Alcala Cotton: 100,000 acres' activity is shown with 3231000 Diesel Gallons and 0 Gasoline Gallons.

Portfolio of Energy Mix									
	California Grid Mix	Natural Gas Power Plant	Oil-Fired Power Plant	Natural Gas Direct Drive	Coal Power Plant	Hydro/ Solar /Wind /Nuclear	Diesel Direct Drive	Biogas Generation	Gasoline Direct Drive
Mix 1	100%	0%	0%	0%	0%	0%	0%	0%	0%
Mix 2	0%	100%	0%	0%	0%	0%	0%	0%	0%
Mix 3	0%	0%	100%	0%	0%	0%	0%	0%	0%
Mix 4	0%	0%	0%	100%	0%	0%	0%	0%	0%
Mix 5	0%	0%	0%	0%	100%	0%	0%	0%	0%
Mix 6	0%	0%	0%	0%	0%	100%	0%	0%	0%
Mix 7	0%	0%	0%	0%	0%	0%	100%	0%	0%
Mix 8	0%	0%	0%	0%	0%	0%	0%	100%	0%

Cultivation and Harvest		
Name of Cultivation and Harvest Activities (e.g., "Pima Cotton; All Field Activities")	Diesel Gallons (annual use)	Gasoline Gallons (annual use)
1		
2		
3		
4	Alcala Cotton: 100,000 acres	3231000
5		0
6		
7		
8		
9		
10		
11		
12		

water applied on the fields is used consumptively. These assumptions illustrate water loss issues that users of the model should think about if they need to input a quantity of water on the start tab that they have not actually measured somewhere.

Diagram 7 Start Tab for a Westlands Water District Scenario Two



We then created a Scenario Two that represents one possible way of permanently following 100,000 acres of cotton-growing land in Westlands. Our Scenario Two assumes that the land reverts to natural habitat and that 75% of the water formerly applied to it is left in the Delta for environmental uses, and 25% of

the water formerly applied to it is no longer pumped from the ground. We arbitrarily assume 200,000 acre-feet per year of source water is saved by following 100,000 acres of cotton, which is equal to 180,000 acre-feet per year applied in the field under the arbitrary assumption in Scenario One that 10%

Diagram 8 Cultivation and Harvest Facility Spreadsheet for a Westlands Water District Scenario Two

The screenshot shows two spreadsheets from a Microsoft Excel application. The first spreadsheet, titled 'Portfolio of Energy Mix', lists eight different energy mix scenarios (Mix 1 to Mix 8) and their percentages for ten different energy sources. The second spreadsheet, titled 'Cultivation and Harvest', lists activities and their corresponding annual usage of Diesel and Gasoline gallons.

Portfolio of Energy Mix									
	California Grid Mix	Natural Gas Power Plant	Oil-Fired Power Plant	Natural Gas Direct Drive	Coal Power Plant	Hydro/ Solar /Wind /Nuclear	Diesel Direct Drive	Biogas Generation	Gasoline Direct Drive
Mix 1	100%	0%	0%	0%	0%	0%	0%	0%	0%
Mix 2	0%	100%	0%	0%	0%	0%	0%	0%	0%
Mix 3	0%	0%	100%	0%	0%	0%	0%	0%	0%
Mix 4	0%	0%	0%	100%	0%	0%	0%	0%	0%
Mix 5	0%	0%	0%	0%	100%	0%	0%	0%	0%
Mix 6	0%	0%	0%	0%	0%	100%	0%	0%	0%
Mix 7	0%	0%	0%	0%	0%	0%	100%	0%	0%
Mix 8	0%	0%	0%	0%	0%	0%	0%	100%	0%

Cultivation and Harvest		
Name of Cultivation and Harvest Activities (e.g., "Pima Cotton; All Field Activities")	Diesel Gallons (annual use)	Gasoline Gallons (annual use)
1		
2		
3		
4 Alcala Cotton: 100,000 acres FALLOWED	0	0
5		
6		
7		
8		
9		
10		
11		

of source water is lost during distribution within the irrigation district. This illustration is overly simplified in a number of ways and DOES NOT represent a real choice faced by Westlands. It is interesting, however, since Westlands is actively discussing the possibility of permanently following 100,000 acres.

Diagrams 7 and 8 show the revised start tab and the revised cultivation and harvest facility spreadsheet used in Scenario Two. These are the only differences in the model between Scenarios One and Two.

Diagram 9A Agricultural Model Output Tab, Lower Third, Left Half

Difference Between Scenarios (Only Non-Zero Values will appear)	AF per Year	Grams/ Year						
		Total organic gases	Reactive organic gases	Carbon monoxide	Nitrogen oxides	Sulfur oxides	Total particulates	Particulates < 10 microns
Sources & Conveyance	(200,000)	(1,993,875)	(478,400)	(6,859,125)	(3,349,775)	(319,150)	(701,025)	(590,200)
Groundwater	(50,000)	(1,993,875)	(478,400)	(6,859,125)	(3,349,775)	(319,150)	(701,025)	(590,200)
Local Surface Water								
Reclamation								
Imported	(150,000)							
Tailwater Reuse								
Water Distribution In The Irr. District	(200,000)							
Customer Use, On-Farm Irrigation Systems	(180,000)							
Drainage Management	(60,000)							
Cultivation and Harvest		(66,752,460)	(52,277,580)	(181,162,170)	(840,964,680)	(55,314,720)	(59,127,300)	(59,127,300)
Total	(640,000)	(68,746,335)	(52,755,980)	(188,021,295)	(844,314,455)	(55,633,870)	(59,828,325)	(59,717,500)

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[Designed by Gary Wolff](#)

Diagrams 9A and 9B show the estimated decrease in energy use and emissions from moving to Scenario Two from Scenario One. The breakdown of emissions by type of water management activity (rows) in Diagram 9A shows that a reduction in imported water does not reduce emissions at all since it was

assumed that imported water was pumped using hydroelectricity. Emissions reductions, under the assumptions made, result from less groundwater pumping (reduced use of electricity from the California Grid) and less cultivation and harvest (reduced use of diesel fuel to power tractors, etc.).

Carbon Dioxide	Energy Use (equivalent Kwh/YR)	Energy Factors (equivalent kwh/af of Customer Use)	Actual Electricity Use (Kwh/YR)	California Grid Mix	Natural Gas Power Plant	Oil-Fired Power Plant	Natural Gas Direct Drive	Coal Power Plant	Hydro/Solar/Wind/Nuclear	Diesel Direct Drive	Biogas Generation	Gasoline Direct Drive	Gasoline for Cul.&Har. (Gallons)	Diesel for Cul.&Harv. (Gallons)
(15,307,500,000)	(107,500,000)	(2)												
(15,307,500,000)	(32,500,000)	(9)	(32,500,000)											
	(75,000,000)	7	(75,000,000)											
(31,272,849,000)	(46,009,440)	(51)												
(46,580,349,000)	(153,509,440)	(53)	(107,500,000)											-3231000.0

Diagram 9B shows that following 100,000 acres could save more than 150 million equivalent kwh per year, under the assumptions made. Of this amount, 107.5 million kwh per year would be electricity

actually supplied by the grid. The remainder of the equivalent kilowatt-hours represents the energy in diesel fuel used directly, rather than indirectly via a power plant.

HOW TO USE THE MODELS

This section describes how to use the Water to Air (WtoA) models available from www.pacinst.org/resources/water_to_air_models in more detail than the general discussion above. The model files are read-only, so you must “save as” to save scenarios and comparisons of scenarios that you create. This manual applies to the models labeled “Version 1.” If other versions are created in the future, updates to the user manual will be available with them at www.pacinst.org/publications. Please direct any questions about the models to Gary Wolff, P.E., Ph.D., at the Pacific Institute (gwolff@pacinst.org or 510-251-1600 x102).

Changing Security Settings

Depending on the version of Excel the user is operating, the security setting may need to be adjusted to enable Visual Basic code. If the user is operating Excel 2000 or an earlier version, then no security adjustment is required. If the user is operating Excel 2002, then a security adjustment must be made prior to running the WtoA Models. To determine which version of Excel you are using, please go to the “Help” prompt and select “About Microsoft Excel.” The top section of the dialog box will inform the user which version of Excel is being used.

For Excel 2002 users, select the “Tools” prompt, then “Macro,” then “Security.” A dialog box will be displayed. Change the security setting to “Medium.”

Overview of the Models

Before we explain how to use the model, some basic overview information is provided. Each WtoA model has six sheets: start, facilities, assumption, engine, summary, and output. The user will only put information in the “Start” tab and possibly in the “Facility” tab if information is available for more than one facility. The only exception to this is in the Agricultural Management Version for the “facility” cultivation and harvest sheet. The user will have to provide information on cultivation and harvest in the “Facility” tab.

All information will only be inputted into white cells with a black border. The user will either input a value or select an option from a dropdown box. All yellow cells display information that cannot be changed. The “Start” tab is where the user can provide information on facilities and run the model. How to run the model will be explained in the next section. The “Assumption” tab provides information on estimates of energy usage by facilities, and air emission levels by energy sources. Also, basic conversion information is stored here. The next tab, “Engine,” calculates emission levels for each facility. In addition, this sheet checks for potential errors. The “Summary” tab summarizes the information depending on the user’s selection. The last sheet, “Output,” displays two scenarios and the difference between them.

Overview of Running the Models

To run either WtoA model, the user must create at least one scenario. A scenario is a description of a water system from sources through disposal (sources, treatment, distribution, customer uses, wastewater treatment). Each scenario is composed of facilities that use energy, the amount of water that flows into each facility, the amount of energy used at each facility, and the sources of energy for each facility. A facility is a place where water is pumped, treated, or used. Groundwater wells, treatment plants, and clothes washers are all facilities. One can input up to 19 named facilities within each category of facilities, such as water treatment plants. A 20th facility (“Other”) is automatically calculated to have flow equal to the total flow for a category of facilities on the “Start” spreadsheet (e.g., water treatment plants), less the specifically named facilities that are input in the corresponding section (in this case, the water treatment plant section) of the facility spreadsheet.

Once the other three types of information (flow, energy use, and energy source) are provided for all facilities in a scenario (detailed instructions are presented below), the user simply selects the appropriate scenario (such as Scenario 1), then presses the “Update Scenario” button. This stores the appropriate information in the “Update” tab. The user is then able to compare this scenario with a second one. The user changes any values they wish, then selects the other scenario button (such as Scenario 2), and then presses “Update Scenario.” After the completion of this task, the energy use, emission levels, and key inputs for BOTH SCENARIOS are displayed in the “Output” tab. The user can view the information, or simply print the tab. Note that this sheet displays three sections, Scenario 1, Scenario 2, and the differences between them. In the differences between scenarios, zero values have been suppressed for visual purposes. Thus if two scenarios are exactly the same, no information will be displayed in the difference between scenarios output.

Detailed Explanation of How to Run the Models

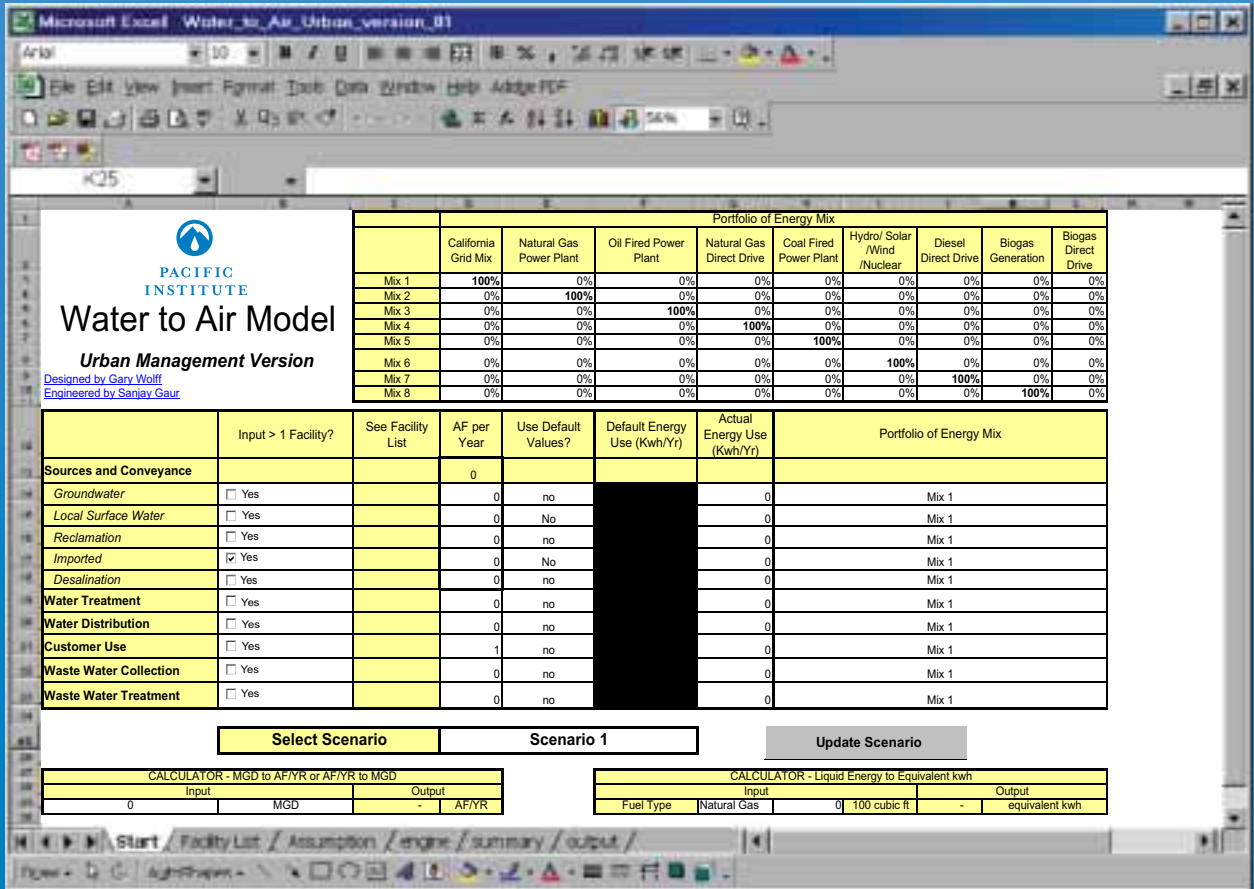
When running WtoA model the first dialog box will ask the user whether to enable or disable macros². The user should select “enable macros.” The second dialog box is a welcome message that asks the user to provide the name of their agency. The user should type in the agency they work for. This information will be automatically displayed in the summary output. Once this information is typed, select OK. The user then will see the “Start” tab or the first input sheet for WtoA. Diagram 10 shows the interface for the Urban Management Version.

It is recommended that the user first select the appropriate energy mixes. As Diagram 10 shows, there are nine different types of energy sources. In addition, the user has the ability to create eight different energy mixes from these nine different sources. A user simply selects the percentage for each energy source that would create a mix that adds to 100%. In Diagram 10, Mix 1 is 100 percent California Grid mix. If a user creates a portfolio of energy sources that does not add to 100 percent, then the cells within that mix will turn red. In addition, the model will not run and an error message will be produced to inform the user to adjust the portfolio.

Once the appropriate energy mixes are selected, then the user should input information about the facilities. There are ten and nine categories of facilities on the “Start” spreadsheets of the Urban Management and Agricultural Management models, respectively.

To provide information on a facility the user simply inputs it. For instance, each facility requires acre-feet per year, a default energy value or actual energy use, and a source of energy (energy mix). If information for only one facility is available for the Urban Management version, it can be input on the “Start” tab. For the Agricultural Management version, however, the user is forced to provide information for cultivation and harvest on another spreadsheet. Once all required information is provided, the user can run a WtoA model. To run it, please see the section “Overview of Running the Model,” above.

² WtoA uses a series of macros or Visual Basic code to run the model.



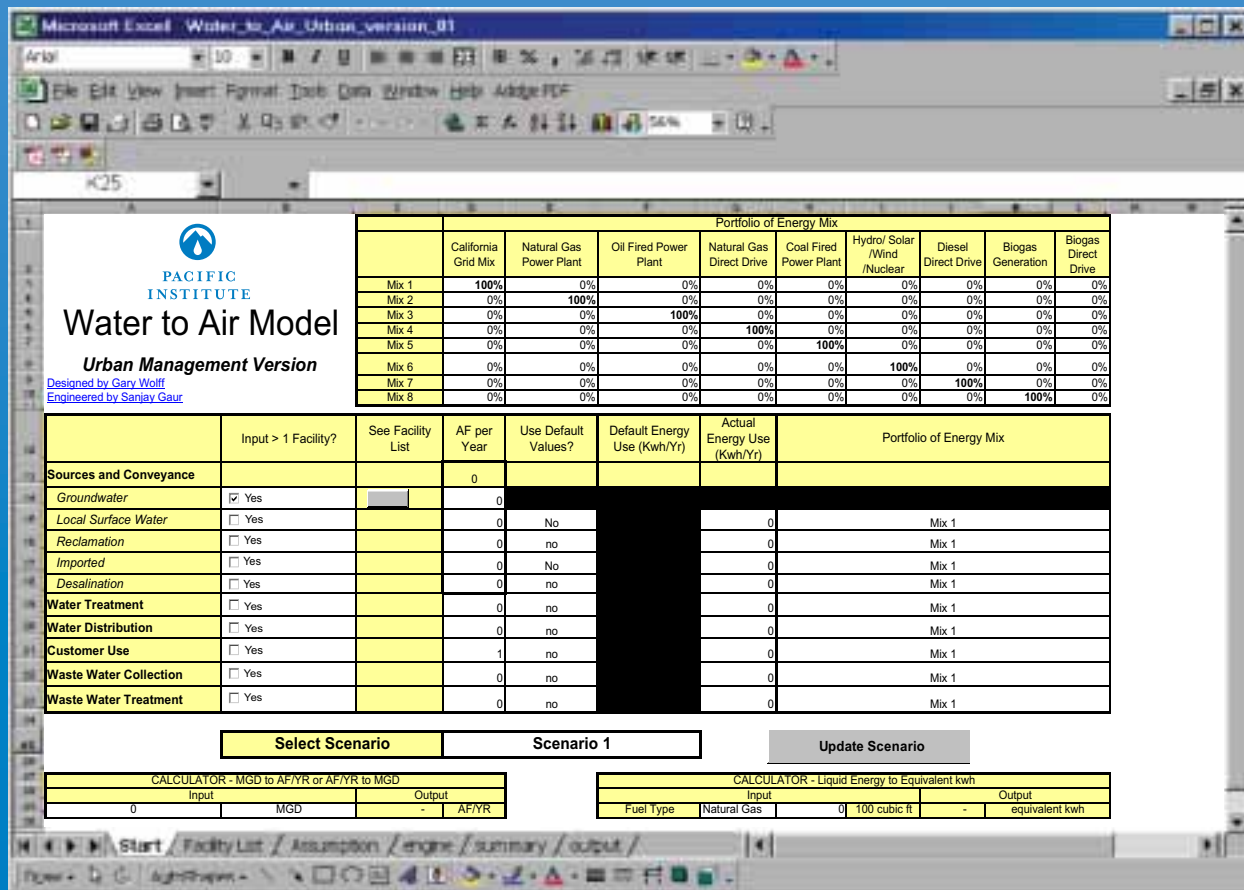
Because water quantity inputs must be in acre-feet per year (af/yr), we've provided a calculator to convert from millions of gallons per day (MGD) to af/yr (or the reverse). After converting MGD to af/yr, you must input the af/yr number manually.

Similarly, energy inputs must be in actual kilowatt-hours (kwh) per year or "equivalent" kilowatt-hours per year. An equivalent kwh is the amount of electricity that could be generated (on average) if a fuel (e.g., natural gas) were used in a power plant to generate electricity. This unit is necessary because sometimes energy other than electricity is used to directly pump or otherwise manage water. For example, natural gas

and diesel fuel are used to directly drive pumps in some places. If you have this type of energy use, you must input equivalent kwh rather than hundreds of cubic feet (cf) or gallons (g) of natural gas or diesel fuel, respectively. Again, we've provided a calculator to make these conversions. After converting from gas or liquid fuels to equivalent kwh, you must input the equivalent kwh in the appropriate row manually.

Conversion errors are common in performing the types of calculations in these models. Please use the calculators provided rather than a hand calculator to prevent such errors.

Diagram 11 Listing More Than One Groundwater Facility

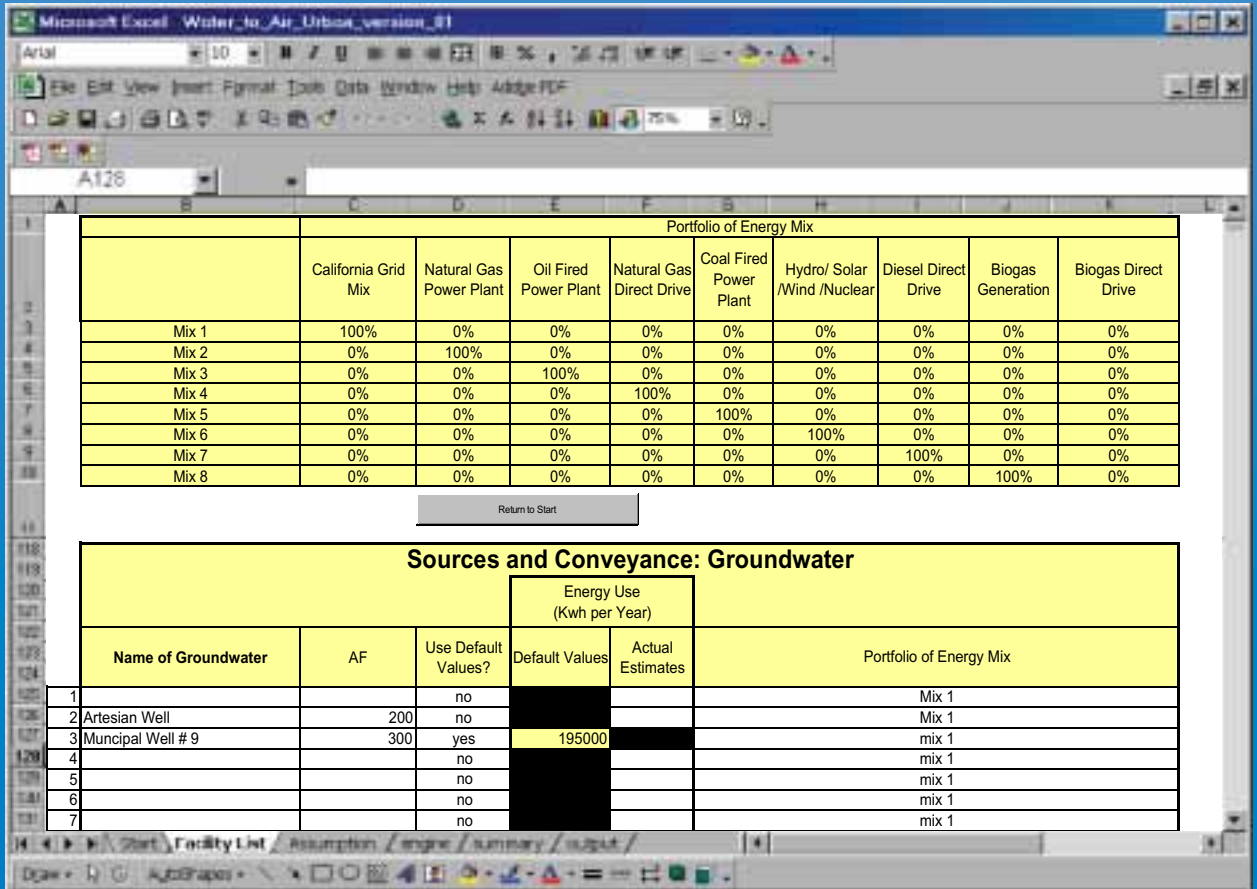


If more than one facility exists in a category, the user should select yes to input all facilities on the facility spreadsheet. For instance, if the user selects yes to “Input >1 Facility?,” this will automatically display a button and disable the following cells for Groundwater in the “Start” tab: Use Default Value, Actual Energy Use, and Portfolio of Energy Mix. See Diagram 11 for a visual display.

The user then selects the button associated with Groundwater, which will automatically move the user to the Groundwater facility section. Diagram 12

shows what the user will see if one selects the “See Facility List” button for Groundwater.

The user can input 19 different Groundwater Facilities. Each facility require information on acre-feet per year (af/yr), whether to use Default Values or Actual Estimates of energy use, and Energy Mix. Also note that the top section of the window displays the energy mixes the user created in the “Start” tab. Once the information is provided the user simply hits “Return to Start” button, which will automatically guide the user back to the “Start” tab.

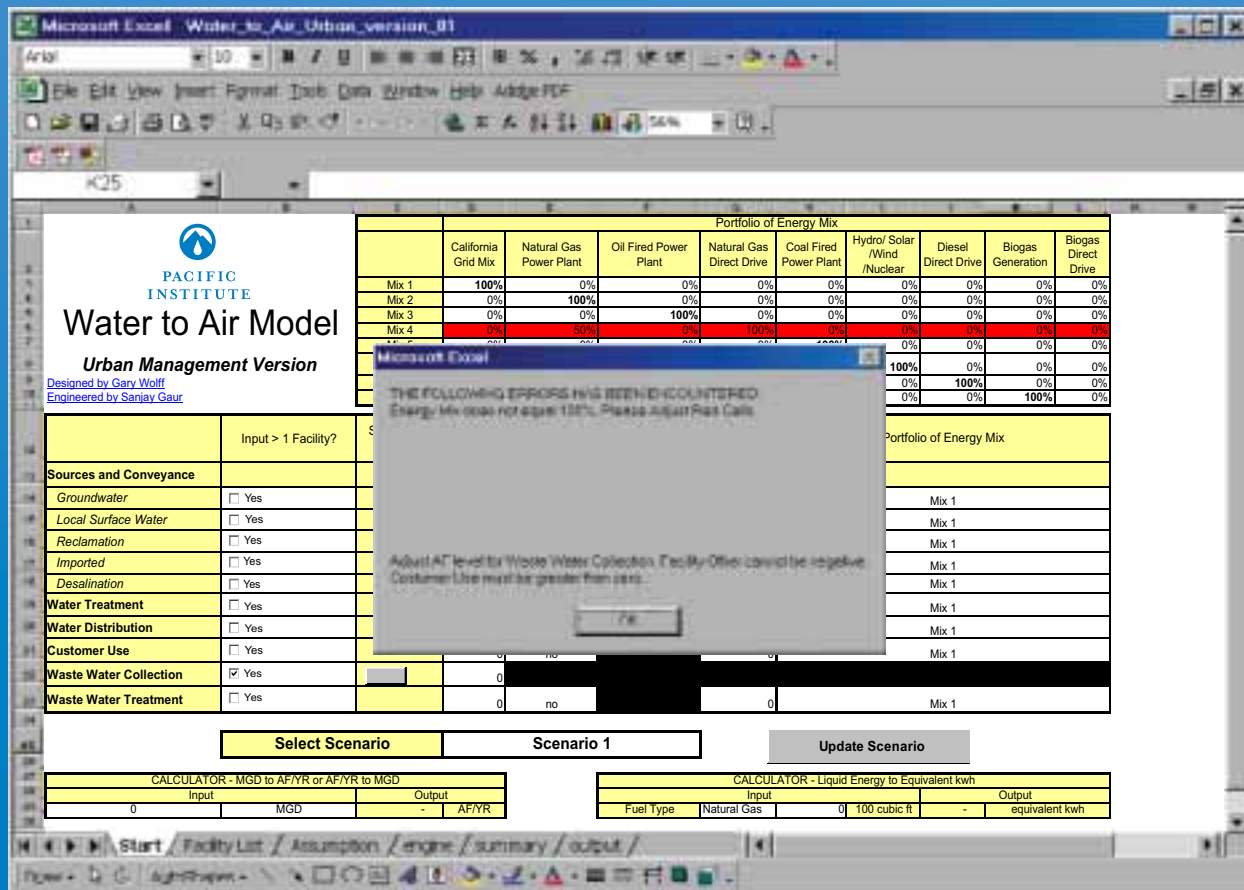


One technical issue needs to be addressed regarding the relationship between the “Start” spreadsheet and the “Facility” spreadsheets. On the “Start” tab the user inputs the total amount of acre-feet of water per year for all facilities in that category, regardless if one has or does not have facility information. If a user has information about more than one facility, then the total amount input on the “Start” tab will be used on the facility worksheet to calculate unaccounted water automatically as facility number 20, “Others.” Theoretically, “Others” can only be zero or positive, since there is no negative acre-feet of water. The

WtoA model will check to ensure that “Other” is not negative for each type of facility during the “Updates of Scenario.”

The only exception to the above rule is for the Agricultural Management version for facility cultivation and harvest. For this type of facility, the user only puts information on the amount of diesel and gasoline that is required for cultivation and harvest in the facility section. That is, totals are not input on the “Start” tab. The facility sheet is an area where the user can list the amount of diesel and

Diagram 13 Error Statements



gasoline used by one or more crop types. The sum of gasoline and diesel that the user inputs into the facility sheet is then automatically displayed in the “Start” sheet.

Once all the appropriate information is in place for facilities on the “Start” and “Facility” spreadsheets, the user is ready to run a WtoA model. Please see the section “Overview of Running the Model,” above, to run a WtoA model.

Error Statements

There are three potential types of error that a user can perform in running the WtoA models: 1) Energy mix does not equal 100%, 2) Facility number 20- “Others” af/yr is a negative value, and 3) Customer water use is zero (Diagram 13). If a user creates one or more of these types of errors, then pushes the “Update Scenario” button, a dialogue box will inform the user that an error has been encountered and the type of error. All three errors are illustrated in Diagram 13.

Since there are three error statements in this example, the user will need to fix all three. The first is adjusting the red-colored energy mix to equal 100 percent (Mix 4 in Diagram 13). Notice that the example allocates 50% to Natural Gas Power Plant and 100% to Natural Gas Direct Drive, which leads to an impossible total of 150% for Mix 3. The user will need to adjust this energy mix so that the sum equals 100%.

The second problem is regarding Waste Water Collection, Facility “Others.” There are two possible sources of this problem. First, the af/yr of water for this category of facilities in the “Start” tab may be too low. In Diagram 13, for example, the total for Waste Water Collection is 0 acre-feet per year, which means that inputting a facility with any positive value (e.g., 1 af/yr) on the facility spreadsheet will force Facility 20 “Others” in the Wastewater section of the Facility spreadsheet to be less than zero (e.g., -1). The second possible problem is that the user has accidentally keyed in a Facility for Waste Water Collection that is far larger than intended (e.g., 1,000

af/yr rather than 100 af/yr). As mentioned, “Others” is simply the difference between the total af/yr input for the Waste Water Collection category of Facilities (on the “Start” tab) and the sum of facilities 1 to 19 in the Waste Water Collection section of the Facility worksheet.

Third, inputting zero customer use will cause a “divide by zero” error on the summary and output sheets in the column labeled “energy intensity.” The models calculate the energy use per unit of water using total customer water use as the denominator (that is, energy intensity is defined as energy use divided by customer water use). Failing to specify positive customer water use not only creates this mathematical problem, but is inconsistent. If the system actually delivered zero water for a year, it wouldn’t use any energy, either.

Once these inputs have been checked and corrected, the user will be able to push the “Update Scenario” button without an error message.

APPENDIX A: SOME ENERGY USE INFORMATION

Model users need to develop their own energy use information in most cases. However, some information that may be useful is listed below. We believe the information is correct, and list sources. Nonetheless, the Pacific Institute is not responsible for errors in the information

or any problems that might result from use of the model. In particular, default values in the models are provided so that users can have a sense of the relative magnitude of energy use for various facilities, but we do not claim that these default values are average or typical.

Table A-1: State Water Project Energy Use

Delivery Point (outlet)	Energy Use; cumulative (facility) (kilowatt-hours per acre-foot)
Banks Pump Station	296 (296)
South Bay Aqueduct	1,093 (797)
Del Valle Reservoir	1,165 (72)
Dos Amigos Pump Station	434 (138)
Buena Vista	676 (242)
Wheeler Ridge	971 (295)
Wind Gap	1,610 (639)
A.D. Edmonston	3,846 (2,236)
Alamo	3,741 (-105)
Pearblossom	4,444 (703)
Mojave Siphon	4,349 (-95)
Devil Canyon Variable	3,236 (-1,113)
Oso	4,126 (280)
W.E. Warne	3,553 (-573)
Castaic	2,580 (-973)

Notes: (1) Energy use is per acre-foot at each facility; that is, it accounts for water losses in transmission prior to that facility.

(2) Source: Wilkinson (2000), p. 29

(3) Cumulative energy use in each row is the sum of all facility energy use figures in that row and above.

Table A-2: Partial List of Central Valley Project Energy Use

Delivery Point	Energy Use; cumulative (facility) (kilowatt-hours per acre-foot)
Tracy Pump Station (4)	238 (238)
Lift from O'Neal Forebay (4)	297 (59)
Lift to San Luis Reservoir	597 (300)
Hydroelectric generation from releases from the San Luis Reservoir (2)	387 (-210)
Dos Amigos Pump Station (5)	435-525 (138)
Pleasant Valley Pump Station (5)	673-763 (238)

Notes: (1) Energy use is per acre-foot at each facility; that is, it accounts for water losses in transmission prior to that facility.

(2) Source: Wilkinson (2000), p. 29

(3) The higher cumulative energy use in each row is the sum of all facility energy use figures in that row and above.

(4) The state water project Banks Pump Station is a parallel path for water en route to the San Luis Reservoir. Its energy use is nearly identical to the CVP pumps.

(5) The lower cumulative energy use is for water that bypasses the San Luis Reservoir.

Table A-3: Diesel and Gasoline Fuel per Acre of Cropland Cultivated and Harvested

Crop	Gallons of diesel fuel used per acre per year (1)	Gallons of gasoline used per acre per year (1)
Alfalfa	15.15	0.53
Almonds, flood irrigated, San Joaquin (SJ) Valley (2)	15.81	5.25
Almonds, sprinkler irrigated, San Joaquin (SJ) Valley (2)	11.66	9.38
Cotton, Alcala, SJ Valley (2)	32.31	0
Cotton, Pima, SJ Valley (2)	37.22	0
Tomatoes, processing, Sacramento Valley (2)	84.32	1.34
Tomatoes, fresh, SJ Valley (2)	46.36	2.08
Wheat	16.71	0.64

Notes: (1) Gallons of gasoline and diesel fuel in cost and returns studies prepared by UC Cooperative Extension, available at www.agecon.ucdavis.edu/outreach/crop/cost.htm

(2) Estimated fuel consumption varies within crop type by location, cultivation practice, species, etc. We've provided three examples to illustrate these types of differences.

Table A-4: Other Relevant Data, Including Sources for Default Values

Type of Facility	Energy Use (equivalent kwh/AF)	Sources
Generic Imported – Urban Model	1,000	Arbitrary but reasonable default value (see Table A-1)
Generic Imported – Agricultural Model	500	Arbitrary but reasonable default value (see Table A-2)
Imported – Colorado River Aqueduct	2,000	Wilkinson (2000)
Hydroelectricity Production Foregone by Imperial Irrigation District (IID) Transfer of Colorado River Water to San Diego County Water Authority	-110	Henrik Olstowski, Superintendent of power generation, IID, personal communication. June 2003
Groundwater	650	See notes 1 and 2
Reclamation	350	See notes 1 and 3
Seawater Desalination	4,500	See notes 1 and 4
Brackish Water Desalination	405; 1,700	See notes 5 and 6
Ocean-Towed Water Bags, 900 mile round trip	1,180	See note 7
Water Treatment	55	See notes 1 and 8
Water Distribution	395	See note 9
Urban End-Use Categories	Various, see Urban WtoA Model	Wolff, et.al. (2004)
Wastewater Treatment	440	Burton (1996), weighted average over a range of facility sizes, activated sludge treatment
Ten Foot Lift for Flood Irrigation	30	See note 10
Low Pressure Sprinklers	100	See note 10
Permanent Set Sprinklers	205	See note 10

Notes: (1) Data from Jeff Stevenson, Water Resources Specialist, San Diego County Water Authority (SDCWA), personal communication. June 2003. (2) Arbitrary but reasonable default value that depends largely on the depth to groundwater. Based on Yuima Municipal Water Authority use at 661 kwh/af; Sweetwater Authority use at 564 kwh/af; and Westlands Water District use at 740 kwh/af. (3) Average of tertiary treatment at three plants in San Diego County: San Elijo (600), Fallbrook #1 (337), and Santee Basin (122). (4) Average of personal communications from John Kiernan of Ionics Corporation for their Trinidad plant (4,800) and Jeff Stephenson of the SDCWA for the proposed Carlsbad plant (4,200). (5) 405 is the Reynolds water treatment plant in San Diego County, which treats brackish groundwater. (6) 1,700 is reported by Wilkinson (2003) for the Chino desalter operated by the Inland Empire Utilities Agency. (7) From tugboat fuel cost data provided by Terry Spragg of Spragg's Bags. Energy expenditure converted to fuel at \$1.50 per gallon, then converted to equivalent kwh assuming the fuel was used to produce electricity in a central power plant. (8) Average of three plants in San Diego County: Perdue (41), Escondido-Vista (48), and Levy (68). (9) From Burton (1996) for treatment and distribution combined (450 kwh/af), less default value of 55 kwh/af assumed for treatment. (10) Calculated by the author from California Energy Commission (2001) for irrigation of grapes and almonds.

APPENDIX B: DOCUMENTATION OF AIR EMISSIONS FACTORS

Air emissions factors were developed using a variety of sources. The factors are based on averages from a limited number of sources and should be both discussed and critiqued for the particular application if the model is used for formal environmental assessments of a water management project (i.e., in an EIR or EIS). When significant uncertainty existed for a particular factor, we used the value that would create the least difference in emissions when shifting energy sources. We felt this type of error was less likely to lead users of the model astray than large but highly uncertain differences in emissions from shifting energy sources. Nonetheless, model users should be aware that differences from shifting sources based on our assumptions may be smaller (or larger) than would occur in particular circumstances.

The California Grid Mix

The California Grid Mix emissions for reactive organic gases (ROG), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter less than 10 microns (PM<10) factors are based on 2004 California Air Resources Board (CARB) data provided by Stephanie Kato of CARB in a personal communication. Total organic gases (TOG) and total particulate matter (PM) were estimated as 416% of ROG and 110% of PM<10, respectively, using conversion factors provided by Larry Hunsaker of CARB in a personal communication. The carbon dioxide grid emissions factor was estimated by the authors using data on state and imported fired generation capacity (natural gas, coal, and biomass) in the 2002 California Energy Commission Net System Power Calculation Report (California Energy Commission 2002).

Natural Gas, Coal, and Oil-Fired Power Plants

Average emissions for natural gas, coal, and oil-fired power plants are also based on data provided by Larry Hunsaker in a personal communication, with one exception. We estimated carbon dioxide emissions for oil based on 35% power plant efficiency. This compares with Hunsaker's assumption of 39% for natural gas power plant efficiency and 25% for coal power plant efficiency. The remainder of the data is for year 2000 in-state electricity production. Since these are the primary sources of emissions from grid electricity, model users can create a mix of these sources (along with hydro/nuclear/solar/wind, which are assumed to have no emissions) that better reflects power provided to them by a local or regional utility or a direct purchase contract, than does the California Grid Mix. Although these data are somewhat dated, we felt it was best to create a model that could accommodate local mixes of electrical sources. Data is easier to update than the model itself.

Adjustment for All Centrally Produced Electricity

Data for emissions for all centrally generated electricity were provided to us per kilowatt-hour (kwh) generated,

not per kwh delivered to customers. According to Mark Layton of the California Energy Commission, the California Energy Commission Demand Analysis office found about 7.5% line losses in a study of 2001 data. Consequently, we divided emissions at central power plants (CA grid mix, natural gas, coal, and oil) by 0.925 so that the emissions factors would reflect emissions per kwh purchased by customers, since this is the data model users will input.

Direct Drive Pumps

Some water pumps are driven directly by internal combustion engines fueled with natural gas or diesel fuel or gasoline or digester gas, rather than by electric motors powered by generators that run on these fuels. Although electricity is not actually generated at pumping locations where natural gas, diesel fuel, gasoline, or digester gas is used to direct drive water pumps, a manageable model structure and meaningful outputs could not be created without estimating emissions factors in grams per “equivalent” kilowatt-hour. Note that model users are required to input energy used in these ways in units of equivalent kilowatt-hours. A conversion calculator is provided in the models for this purpose.

We obtained data for direct drive natural gas, diesel, and gasoline prime movers from US EPA’s “Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition.” Tables 3.2-2 and 3.2-3 describe emissions from uncontrolled 4-stroke lean-burn and rich-burn engines, respectively. Table 3.3-1 describes emissions from uncontrolled gasoline and natural gas industrial engines.

Direct Drive Natural Gas

We used the lower of the two factors from Tables 3.2-2 and 3.2-3 as the source data for our “direct drive natural gas” emissions factors. The higher numbers, which are not consistently from either the lean-burn or rich-burn table, are so high we felt they might lead model users astray. Emissions from direct drive facilities, however, are an important topic for further research. Uncontrolled emissions from such facilities may in fact be higher, at least in some

important cases, than we used in the models. We converted emissions data in the various sources cited from units of pounds per million British thermal units (lbs/MMBTUs) into units of grams per equivalent kwh by multiplying by 454 grams per pound, and assuming heat energy is converted to drive shaft energy at 30% efficiency. (Unlike natural gas power plants, which are usually gas turbines, direct drive natural gas pumps are usually driven by internal combustion engines.)

We used emissions data on total organic compounds (TOC) and volatile organic compounds (VOC) as proxies for TOG and ROG emissions. Although these measures are not strictly comparable, they are similar enough that we felt including them in the model was appropriate. Again, it is easier to adjust emissions factors later than it would have been to exclude some energy sources in the model structure now, then redesign it later if better data were available. According to EPA’s footnotes to the tables, total particulates (PM) are equal to the sum of filterable and condensable particulates, and PM<10 is the same as PM since all particulates from gas combustion are small. Finally, we assumed that SOx emissions for direct drive natural gas pumps were the same as from average natural gas power plants because the SOx emissions estimates in Tables 3.2-2 and 3.2-3 were much lower than natural gas power plant emissions in California. We found that implausible, and noted that EPA’s estimate was a calculation from an assumed sulfur content for natural gas that might be incorrect for California.

Direct Drive Diesel and Gasoline

Table 3.3-1 of AP-42 provides emissions factors from uncontrolled diesel and gasoline engines in pounds per horsepower-hour. We converted these factors into grams per equivalent kilowatt-hour by multiplying by 0.608, as recommended in a footnote to the table. Again, PM was assumed equal to PM<10 by EPA assumption listed in a footnote, and TOC in engine exhaust was used as a proxy for TOG. We estimated ROG/VOC as a percent of TOC equal to the ratio of ROG to TOG in oil-fired central power plant emissions (about 78%).

Direct Drive Digester Gas

Emissions factors for pumps driven directly by engines using digester gas were assumed equal to those from electricity generated with digester gas (below), with one exception. Direct drive does not experience an efficiency loss between shaft power and generator output. We therefore assumed emissions from digester gas used directly were 5% less than from digester gas used to generate electricity.

Electricity Generated With Digester Gas

Many wastewater treatment plants generate electricity using digester gas, sometimes blended with natural gas to ensure more even combustion. Resources did not allow a thorough investigation of emissions from these facilities. We did obtain, however, data from the East Bay Municipal Utility District (EBMUD) for the three 1,850 kw internal combustion engine-generators at their wastewater treatment plant. This data was consistent and in our opinion usable for emissions of CO, NO_x, and filterable particulates. We used direct drive natural gas emissions factors for the other categories, except carbon dioxide, but adjusted upward to reflect a 5% loss in drive shaft energy as it is converted to kwh in the generators.

Finally, carbon dioxide emissions per kwh are higher for digester gas driven engine-generators than natural gas driven engine-generators because 40% of digester gas (typically) is carbon dioxide that is emitted but does not contribute to production of electricity. The remainder of the digester gas, plus 10% natural gas blended with digester gas, is essentially methane, which creates the same amount of carbon dioxide per kwh generated as would pure natural gas. As a result, the carbon dioxide emissions factor for digester gas is equal to the emissions for direct drive natural gas, adjusted upward to reflect a 5% loss in generation, plus the carbon dioxide that was present in the digester gas to start with. The latter is equal to about 340 grams per kwh based on the digester gas feed rates, density of carbon dioxide at 70 degrees Fahrenheit, and power output reported by EBMUD.

Energy Used for Crop Cultivation and Harvest

The agricultural model includes emissions from on-farm diesel and gasoline-powered equipment (e.g., tractors) used to cultivate soil and harvest crops, because Wolff, et.al. (2004) found that these types of changes in energy use due to changes in on-farm water management were significant. Including these types of emissions in the agricultural model allows one to estimate impacts from land fallowing or crop shifting that may be associated with water conservation on farms.

Table 3.3-1 in AP-42 also provides emissions factors for gasoline and diesel fuel in units of pounds per million BTUs. Multiplying by 454 and dividing by 0.13 million (130,000) BTUs per gallon of diesel fuel and 0.115 million (115,000) BTUs per gallon of gasoline yields emissions factors per gallon of each of these fuels. As above, PM and PM<10 are assumed equal, TOC in exhaust is used as a proxy for TOG, and ROG/VOC is estimated as 78% of TOC (the ratio of ROG to TOG in oil-fired power plant emissions).

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654 13th Street, Preservation Park, Oakland, California 94612
telephone 510-251-1600 • telefax 510-251-2203
www.pacinst.org

