Environ. Sci. Technol. **2010,** *44,* 2126–2130

Direct and Indirect Water Withdrawals for U.S. Industrial Sectors

BY MICHAEL BLACKHURST, CHRIS HENDRICKSON,[1] AND JORDI SELS I VIDAL

Department of Civil and Environmental Engineering, Green Design Institute Carnegie Mellon University, Pittsburgh, PA

Received July 2, 2009. Revised manuscript received December 23, 2009. Accepted January 5, 2010.

Effective water management is critical for social welfare and ecosystem health. Nevertheless, information necessary to meaningfully assess sustainable water use is incomplete. In particular, little information is available on supply chain or indirect water use for the production of goods and services in the United States. We estimate a vector of water withdrawals for all 428 sectors in the 2002 U.S. economic input−output table. The vector was applied using economic input−output life cycle assessment (EIO−LCA) methods to estimate direct and indirect water withdrawals for each sector's production, both in terms of total withdrawals and per dollar of output. Agriculture and power generation account for an overwhelming majority of direct water withdrawals (90%). A majority of water use (60%) is indirect ("embodied" or "virtual" water) with 96% of the sectors using more water indirectly in their supply chains than directly. The food and beverage industry accounts for 30% of indirect withdrawals. These results can be useful for environmental life cycle assessment of U.S. production and other studies, especially to avoid truncation errors due to boundary setting associated with process based life cycle impact assessments. However, we conclude that better information on water use would be helpful for effective water management.

1. Introduction

The attention paid to water management varies considerably from region-to-region, reflecting local scarcities, water prices and ecological health concerns. Variation also occurs among industries, reflecting industrial needs and impacts. Water rights, under the jurisdiction of states in the U.S., also vary regionally, often reflecting historical patterns and trades. In the U.S., attention to water supply management is much greater in arid regions, such as the Colorado River basin, compared to the Ohio River basin, where water quality is of more concern. The information available on water use likewise varies from region to region. Little information is available on supply chain or indirect water use for the production of goods and services.

Metrics and methodologies for modeling sustainable water use are becoming more available in the literature. Some researchers advocate using indicators in a press-state-response framework for assessing sustainable water use (*1*, *2*). Pressure-state-response methods are data intensive, require the development of custom indicators, and do not readily accommodate supply chain analyses. Process LCA modeling software, such as Simapro (*3*) can be suitable for process assessments; however, such software is not suited for regional and national scale policy assessments.

Defining appropriate life cycle inventories and impact assessment can be particularly challenging in assessing water use. Fresh water is a locally renewable but globally finite resource. Hydrologic forces—such as evapotranspiration, rainfall, and surface runoff—move freshwater in time and space. Industrial water users may return withdrawn water to its original watershed. However, water quality may be impaired such that downstream uses are limited. These factors complicate explicit and clear definitions of water use inventories and impact assessments (*4*).

Owens (*5*) presents categories of water use that depend upon the renewability of the water resource, in-stream or off-stream withdrawals, and whether or not withdrawn water is "consumed." The FAO (*6*) also provides helpful definitions of water use for life cycle modeling.

Udo de Heas (*7*) indicates that regional variations and LCA modeling structures limit impact assessments for water use. We concur and add that temporal variations in water use, diverse quality impacts, and diverse downstream quality requirements make life cycle impact assessment difficult.

Even with adequate and acceptable definitions of water use, the data available typically do not align with such definitions. The most recent detailed survey of U.S. industrial water use was done in 1982 by the U.S. Census (*8*). The 1982 census reported four categories of water use (withdrawal or intake, recirculated or reused, untreated discharge, and treated discharge) for standard industrial classification (SIC) sectors. This SIC system was replaced by the current North American Industry Classification (NAICS) system in 1997. Regional water use inventories are occasionally prepared by states, especially in arid climates. However, such inventories are not necessarily suitable for life cycle assessments.

In this paper, we estimate national water withdrawals by industrial sector based upon United States Geological Survey (USGS) totals, without considering amounts of water returned to the watershed.

Few economic input−output life cycle assessment studies of water use have been completed. Lenzen (*9*) prepared the most complete study, tracking "virtual water flows" in the Australian state of Victoria using 344 economic sectors. Hubacek (*10*) provides a summary of previous input output efforts to track water use.

In this paper, we estimate water withdrawals (also called "use" here) for the 426 sectors of the U.S. 2002 economic input−output table (*11*). The type of water use, source of the water, and geographic location of use would also be of interest for environmental impact assessment (*12*). Nevertheless, national averages of water use by industry are useful. In particular, this water use vector can be coupled with the U.S. economic input−output model to develop estimates of direct and indirect water use for U.S. industrial production (*13*−*15*).

The economic input−output model itself is routinely used in forming the national accounts and for employment impact assessments from new investments. The coupling between economic input−output models and resource use or environmental emissions permits tracing a wide variety of effects associated with the production of goods and services. The resulting EIO−LCA software (*13*) has been widely used in life cycle inventory and assessment studies. In this paper, we develop a means to provide a inventory of supply chain water use which could be used in more comprehensive assessment studies.

[1] Corresponding author phone: 412-268-1066; fax: 412-268-7813; e-mail: cth@cmu.edu.

10.1021/es903147k

Published on Web 02/08/2010

TABLE 1. Total Water Withdrawals by Category and Allocation Data for Each Category, As Reported by United States Geological Survey 2000 (*16*)

USGS sector	allocation factor or method	USGS 2000 direct use estimate billion gal. (teraL)	water use (%)	allocation data reference(s)	year of allocation data
power generation	allocated to the power generation sector	71 000 (270)	47.8%		
irrigation	yields and irrigation rates reported by usda surveys	50 000 (190)	33.6%	USDA 2004a (*17*) USDA 2004b (*18*)	2002−2003
non-domestic public supply*	2002 purchases from "Water, sewage and other systems" sector	6500 (25)	5.1%	BEA 2009 (*11*)	2002
Industrial	By employee as reported by Canada	7200 (27)	4.8%	StatCan 2008 (*19*) Industry Canada (*20*) BLS (*21*)	2005
live-stock and aquac-ulture	yields and irrigation rates reported by USDA surveys	2040 (7.7)	1.3%	USDA 2004a (*17*) USDA 2004b (*18*)	2002−2003
Mining	By employee as reported by Canada	1300 (4.9)	0.94%	Gleick (*22*), EIA (*23*) Ripley (*24*) Birchfield (*25*) Rutherford (*26*) NRC (*27*), BLS (*21*) Mudd (*28*), Gelt (*29*) Census (*30*), Kelly (*31*)	2002−2008
domestic water use	not allocated to an industrial sector	1300 (4.9)	0.9%		
	total	140 000 (532)			

In the following section, our method of water withdrawal estimation is briefly described, followed by an overview of estimated direct and indirect water use for sectors. A final section discusses the uncertainty in our estimates and alternatives to the estimation process presented here. The Supporting Information (SI) describes the estimation method in more detail and presents the complete estimated vector.

2. Estimation of Direct U.S. Water Withdrawals for Each Economic Sector. The United States Geological Survey (USGS) estimates water use for seven aggregate categories (Table 1) (*16*). Since detailed information on industrial sector water use is not available, each USGS category is allocated to sectors in the economic input output table or to residential water use not represented by an industrial sector. Residential or domestic water use, which constitutes 23 300 billion gallons per year (88 000 gigaliters) or 6.4% of total withdrawals, represents final demand and was not allocated to any industrial activity. Aside from this adjustment, the allocations presented here maintain USGS category totals. For each USGS category, the allocation calculation was

$$c_{si} = u_i \times (a_{si}/\Sigma a_{si}) \tag{1}$$

where c_{si} is direct water use for sector s from category *i*, u_i is the USGS direct use water withdrawal estimate for category i, and a_{si} is an allocation factor for sector s for category i. The final vector of estimated water withdrawals is the sum of each of the separate category allocations (w_{si}). In order from largest to smallest category of use, the various USGS categories (i) and allocation sources are as follows.

"Power Generation" water use was allocated directly to the *Electric power generation, transmission, and distribution* sector. This water use does not include in-stream use, such as hydro-electric power generation, and represents the largest category of use reported by USGS (48%). Power generation water use is primarily for cooling water and much of it is returned to the natural system, although there are evaporative losses in storage reservoirs.

"Irrigation" water use is 34% of the total and was allocated to 10 agricultural economic sectors based upon reported use of water by farms sampled in United States Department of Agriculture (USDA) surveys (*17, 18*).

"Public supply" water is provided by government entities or private providers for fees through water distribution networks. Public supply water use was reduced by the amount of residential (household) water use as residences do not represent an economic sector in the input−output model. The remaining public supply water was allocated to 379 economic sectors based upon their share of purchases from the *Water, sewage and other systems* sector. For several government sectors with unreported purchases, comparable rates of purchase for similar service sectors were used for allocation.

"Industrial" water use consists of self-supplied water taken from streams or wells and represents 5% of all water withdrawals. This use was allocated to 30 industrial sectors based upon reported self-supplied water use per employee in Canada. For these 30 industrial sectors, we assume that relative use of self-supplied water would be similar in Canada and the United States.

"Livestock" and "aquaculture" self-supply water was allocated to four animal production sectors using the same allocation method as for irrigation water.

"Mining" self-supplied water was allocated among the 10 mining sectors using a mix of process data, employee allocations, and the same allocation method as for industrial water use.

Domestic water use is self-supplied water from streams or wells that is used by individual households. Since households are included in final demand in the economic input−output model, this 1% of water use was not included in the industrial water withdrawal vector.

The various allocation sources are summarized in Table 1. Residential use amounts to 23 300 billion gal/day and is not included in the final input−output vector since it is not an industrial user. A table of the estimated water use and

TABLE 2. Direct and Largest Indirect Water Withdrawals for $1 of final Demand "Sugar Cane Mills and Refining" and Commodity Price of 5 Lb of Refined White Sugar ($ 0.06/5 lb, (*36*))[a]

sector name	water withdrawals Gal./$ (l./$)	water withdrawals (gal./5 lb. bag)
direct use		
sugar cane mills and refining	0.082 (3.1)	0.026
indirect, supply chain uses		
sugar cane and sugar beet farming	270 (1022)	84
power generation and supply	11 (42)	3.4
grain farming	2.4 (9.1)	0.75
pesticide and other agricultural chemical manufacturing	0.39 (1.5)	0.12
cotton farming	0.28 (1.1)	0.087
paperboard mills	0.25 (0.95)	0.078
other indirect uses (remaining 419 sectors)	1.3 (4.9)	0.40
total, all sectors	283 (1071)	88

[a] Values subject to rounding. (calculated by authors).

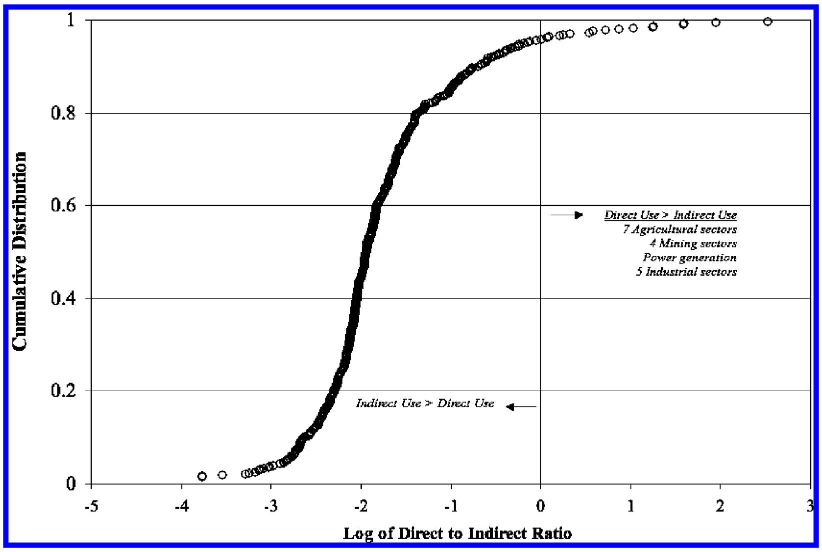

FIGURE 1. Cumulative distribution of direct to indirect water use ratio for economic sectors

water use per dollar of output for each of the 426 input−output industrial sectors is included in the SI.

3. Direct and Indirect Water Withdrawals by Sector. As developed originally by Leontief (for which he received the Nobel Prize in Economics) (*14*), the supply chain inputs for any particular output can be estimated from the economic input−output model available from the U.S. Bureau of Economic Analysis (*11*). The economic input−output model reflects the intersector purchases required for production. For example, livestock production would require purchases of feed from sectors such as grain farming. In turn, the supply chain production can be multiplied by the water withdrawals per unit of production for each sector to obtain an estimate of the supply chain or indirect water withdrawals associated with a good or service. Thus, direct and indirect water withdrawals for sector production can be estimated from the withdrawal vector described above, a vector of sector output, and the economic input output model as

$$\mathbf{w} = (I - A)^{-1}\mathbf{x}F \qquad (2)$$

where $\mathbf{w}$ is a sector vector of water use due to the purchase $\mathbf{x}$, I is the unit matrix, A is the economic input−output matrix, $\mathbf{x}$ is a vector of purchases, and F is a matrix with diagonal elements equal to water use per dollar of output for each sector (*9, 14*). Direct water use consists of water use by the sector itself (including water provided to the sector by providers), whereas indirect water use is water used in the supply chain of the sector.

As an example, Table 2 illustrates the direct and indirect water use calculated from eq 2 for $1 of production in the "sugar cane mills and refining" sector. Table 2 also reports direct and indirect water use for a typical 5 lb (2.27 kg) bag of sugar. The bulk of water use for this sector is indirect, with about 95% of water used in sugar cane and beet farming in the supply chain for sugar production. Power generation, grain farming, and pesticide manufacturing are much smaller indirect water users, with near negligible water withdrawals reported for all upstream sectors except sugar cane farming. For example, indirect use of paperboard for bagging sugar is only 0.1% of water withdrawals. Disaggregating the indirect uses further from the economic sectors shown in Table 2 would require hybrid models including both economic sector and specific process models (*14*).

Sugar refining is typical in that most input−output sectors use more water indirectly than they do directly. Figure 1 shows the cumulative distribution function of the ratio of direct to indirect water use for all 426 sectors. For 93% of sectors, supply chain water use exceeds direct use.

Table 3 shows the total water use for the sector's 2002 entire economic production for the largest 10 water use sectors. For example, Cattle ranching and farming used a total of 8280 billion gallons (31.3 teraL) in 2002 either directly or indirectly in its supply chain. The largest water users were power generation and agricultural sectors, with several commercial sectors also demonstrating significant water withdrawals.

TABLE 3. Direct and Indirect Water Use for the Largest User Sectors - 2002 Economic Output[a]

sector name	total water billion gal (teraL)	direct water billion gal (teraL)	indirect water billion gal (teraL)	direct/ indirect
power generation and supply	62 900 (238)	62 700 (237)	183 (0.69)	343
grain farming	36 200 (137)	35 800 (136)	399 (1.51)	90
food services and drinking places	8970 (34.0)	200 (0.76)	8770 (33.2)	0.023
animal (except poultry) slaughtering and processing	8690 (32.9)	16 (0.06)	8680 (32.9)	0.0018
general state and local government services	8530 (32.3)	1900 (7.20)	6620 (25.1)	0.29
cattle ranching and farming	8280 (31.3)	2440 (9.20)	5850 (22.1)	0.42
other animal food manufacturing	5770 (21.8)	139 (0.53)	5630 (21.3)	0.025
poultry and egg production	5680 (21.5)	32 (0.12)	5650 (21.4)	0.0056
fruit farming	5160 (19.5)	4890 (18.5)	277 (1.05)	18
real estate	5140 (19.5)	326 (1.23)	4820 (18.2)	0.068

[a] Note that the total water use is the sum of the direct and indirect use.

TABLE 4. Direct and Indirect Water Use per Dollar of Output for the Largest Economic Sectors of Water Use per Dollar[a]

sector	total use	total gal (L)/$	direct use	direct gal (L)/$	indirect use	indirect gal (L)/$	direct/ indirect
grain farming	1400	(5000)	1400	(1,900)	34	(22)	41
cotton farming	1300	(5000)	1300	(1,900)	14	(49)	93
sugar cane and sugar beet farming	830	(3100)	810	(1480)	21	(38)	39
tree nut farming	500	(1900)	470	(950)	26	(53)	18
fruit farming	480	(1820)	450	(870)	26	(49)	17
flour milling and malt manufacturing	470	(1780)	0.082	(0.11)	470	(640)	0.000174
power generation and supply	450	(1700)	0.87	(610)	450	(1.7)	0.0019
wet corn milling	380	(1440)	0.065	(1.1)	380	(610)	0.00017
beet sugar manufacturing	330	(1250)	8.0	(0.09)	320	(530)	0.025
vegetable and melon farming	280	(1060)	0.082	(450)	280	(42)	0.00029
other animal food manufacturing	270	(1020)	1.5	(10)	270	(420)	0.0056
sugar cane mills and refining	270	(1000)	240	(0.10)	22	(350)	11
poultry and egg production	250	(900)	250	(1.8)	0.73	(320)	341
dog and cat food manufacturing	200	(800)	58	(7.6)	140	(250)	0.41
cattle ranching and farming	190	(700)	1.7	(72)	190	(170)	0.0089
fiber, yarn, and thread mills	180	(700)	5.3	(2.2)	170	(240)	0.031
tortilla manufacturing	140	(500)	0.24	(0.31)	140	(220)	0.0017
milk production	140	(500)	0.20	(7.6)	140	(190)	0.0014
paint and coating manufacturing	140	(500)	120	(170)	16	(24)	7.5
frozen food manufacturing	130	(500)	15	(0.33)	120	(200)	0.13

[a] Values subject to rounding.

Finally, Table 4 shows the direct, indirect and total water use for the sectors having the largest water use per dollar of output. Agricultural sectors dominate water use per dollar of output, although some manufacturing sectors also appear in Table 4.

EIO−LCA methods also track the pervasiveness of a particular activity throughout the supply chain. Power generation and grain farming were top-10 water users in the supply chain of almost every other economic sector in the 2002 U.S. economy. These sectors accounted for 41% of total water use. Cotton farming, paperboard mills, and paint and coating manufacturing were top-10 water users in the supply chain of most sectors; however, these sectors constitute only 2.5% of total use.

4. Discussion

Total predicted 2002 direct withdrawals (140 000 billion gal or 530 teraliters) are 50% of the flow of the three largest rivers in the continental United States (*32*). As with worldwide water use generally (*22, 34*), a majority of U.S. withdrawals are associated with agricultural activities, food processing, and power generation. Grains and animal products are significant water users; however, animal products are more economically efficient in that they use less water per dollar of output across the product supply chain.

A majority (60%) of water use is indirect. In addition, 96% of U.S. IO sectors use more water indirectly than directly. These results indicate that truncation errors associated with water use life cycle impact assessments could be significant.

The results presented here are subject to considerable uncertainty and underlying variability. For example, the USGS water use data is estimated for the year 2000, whereas the economic input−output table is estimated for the year 2002. Moreover, the USGS water use totals themselves have considerable uncertainty as they rely on state agency estimates. Different agencies use different methods to estimate water use and come to different values. For example, USDA irrigation water estimates for crops (*17, 18*) are 60% of the USGS crop irrigation total. Our allocation methods are also imperfect, introducing additional errors. As a result, we estimate that the water use data is only accurate to a single significant digit.

Our results apply to the national scale only. We caution practitioners against using our results for regional analyses given regional variation in hydrologic and industrial or agricultural practices. For example, the USDA's Irrigation Survey (*18*) indicates that irrigation rates can vary regionally by more than an order of magnitude. Regional EIO−LCA models may produce more accurate regional EIO−LCA results. Methods for developing and applying regional models can be found in Cicas (*35*).

For use in life cycle assessments, we would recommend the use of hybrid methods. Hybrid methods combine process data for the region or plant of interest with national averages, such as those documented here. The degree of indirect water use demonstrated by many sectors necessitates applying system boundaries that extend upstream of secondary suppliers, emphasizing the importance of EIO in water use LCA's.

More direct information on water use would be helpful, including different categories of use, such as water withdrawals and consumptive use. Such data is available for many other countries, such as the Canadian data used in our industrial self-supply allocation (*18*). The U.S. Census Bureau did collect and report industrial water use data up until 1982, but this question was dropped to reduce costs. Our results demonstrate substantial differences from the 1982 data, highlighting the need for more meaningful and accurate national water use data. Given the increasing importance of water for economic development, it would be helpful if the water use questions were reinstated in the Census.

Life cycle impact assessments would be improved with a more stringent definition of the water impacts as well as a better characterization of use. Supply impacts to water vary in time and space; water quality impacts vary in severity, time, and space. Agencies with jurisdiction over water are encouraged to develop standard conventions and nomenclature for tracking and reporting water use.

Acknowledgments

This work was supported in part by the National Science Foundation by a grant from the Material Use, Science, Engineering and Society: Award No. 0628084 and the Green Design Consortium at Carnegie Mellon University.

Supporting Information Available

Details of the water allocation methods and the estimated water use vector. This material is available free of charge via the Internet at http://pubs.acs.org.

Literature Cited

(1) Walmsley, J. J. Framework for measuring sustainable development in catchment systems. *Environ. Manage.* 2002, *29*, 195−206.

(2) Lundie, S.; Peters, G. M.; Beavis, P. C. Life cycle assessment for sustainable metropolitan water systems planning. *Environ. Sci. Technol.* **2004**, *38*, 3465–3473.

(3) PRé Consultants, SimaPro, Version 7.1. www.pre.nl/simapro (2009).

(4) Koehler, A. Water use in LCA: managing the planet's freshwater resources. *Int. J. Life Cycle Assess.* **2008**, *13* (6), 451−455, http://www.springerlink.com/content/1841945144203573/fulltext.html, DOI: :10.1007/s11367-008-0028-6.

(5) Owens, J. W.,Water resources in life-cycle impact assessment: considerations in choosing category indicators. *J. Ind. Ecol.* **2001**, 37−54, DOI: http://dx.doi.org/101162/10881980152830123.

(6) Food and Agriculture Organization of the United Nations. AQUASTAT program, http://www.fao.org/nr/water/aquastat/main/index.stm (2009).

(7) Udo de Haes, H. A.; Heijungs, R.; Suh, S.; Huppes, G. Three strategies to overcome the limitations of life-cycle assessment. *J. Ind. Ecol.* **2004**, *8*, 19.

(8) U.S. Census Bureau, Census of Manufactures 1982, Water use in manufacturing. 1984, 1(3).

(9) Lenzen, M. The virtual water cycle of Victoria, Report on Consultancy. Integrated Sustainability Analysis. The University of Sydney, School of Physics. http://www.isa.org.usyd.edu.au/publications/ISA_VirtualWater.pdf, 2006.

(10) Hubacek, K. L. Sun, Economic and societal changes in China and their effects on water use: a scenario analysis. *J. Ind. Ecol.* **2005**, *9*, 187–200.

(11) BEA (Bureau of Economic Analysis), 2002 Benchmark Input-Output Data, U.S. Census, http://www.bea.gov/industry/io_benchmark.htm, 2009.

(12) Pfister, S.; Koehler, A., S. Hellweg. Assessing the environmental impacts of freshwater consumption in LCA. *Environ. Sci. Technol.* **2009**, *43* (11), 4098–4104.

(13) CMU (Carnegie Mellon University), EIO-LCA (Economic Input-Output Life Cycle Assessment), http://www.eiolca.net/cgi-bin/dft/display.pl (2009).

(14) Hendrickson, C. T.; Lave L. B.; Matthews H. S. *Environmental Life Cycle Assessment of Goods and Services: An Input-Output Approach*; Resources for the Future Press: London, 2005.

(15) Lave, L. B.; Cobas-Flores, E.; Hendrickson, C. T.; McMichael, F. C. Using input-output analysis to estimate economy-wide discharges. *Environ. Sci. Technol.* **1995**, *29*, 420–426.

(16) Hutson, S.; Barber N.; Kenny J.; Linsey K.; Lumia D.; Maupin M. *Estimated Use of Water in the United States in 2000*; U.S. Geological Survey, U.S. Department of the Interior: Washington, DC, 2004.

(17) USDA (U.S. Department of Agriculture), Census of Agriculture (2002), http://www.agcensus.usda.gov/ (2004a).

(18) USDA (U.S. Department of Agriculture), Farm and ranch irrigation survey (2003), http://www.agcensus.usda.gov/Publications/2002/FRIS/index.asp (2004b).

(19) StatCan (Statistics Canada), Industrial water use 2005, Environment Accounts and Statistics Division. Catalogue no. 16-401-X. 2008.

(20) Industry Canada, Canadian industry statistics, http://www.ic.gc.ca/eic/site/cis-sic.nsf/eng/Home (Accessed 2009-06-04).

(21) Bureau of Labor Statistics, Quarterly census of employment and wages (2002). U.S. Department of Labor. http://www.bls.gov/cew/#databases (Accessed 2009-06-05).

(22) Gleick, P. H. Water and energy. *Annu. Rev. Energy Environ.* **1994**, *19* (1), 267–299.

(23) Energy Information Administration. U.S. Department of Energy, Annual energy outlook 2002 with projections to 2020 http://eia.doe.gov/oiaf/archive/aeo02/ (2009).

(24) Ripley E. A.; Redmann R. D.; Crowder A. A., *Environmental Effects of Mining*; CRC Press: Boca Raton, FL, 1996.

(25) Birchfield, G.,Canadian minerals yearbook 2003, Natural Resources Canada. Catalogue no. M38-5/53E-PDF. http://www.nrcan.gc.ca/mms-smm/busi-indu/cmy-amc/2003cmy-eng.htm (2004).

(26) Rutherford, S., Groundwater use in Canada, West Coast Environmental Law, Nov. 2004. http://www.wcel.org/wcelpub/2004/14184.pdf.

(27) *Canadian Minerals Yearbook*; Natural Resources Canada (NRC) 1988, Catalogue no. M38-5/37E. http://www.nrcan.gc.ca/smm-mms/busi-indu/cmy-amc/arch-arch/1988-eng.pdf.

(28) Mudd, G. M., Resource consumption intensity and the sustainability of gold mining, *Proceedings of the 2nd International Conference on Sustainability Engineering & Science*, Auckland, New Zealand, February 2007. http://civil.eng.monash.edu.au/about/staff/muddpersonal/2007-SustEngSci-Sust-v-Gold-Mining.pdf.

(29) Gelt, J.; Henderson, J.; Seasholes K.; Tellman B. ; Woodard G.; Carpenter K.; Hudson C.; Sherif S. *Water in the Tucson Area: Seeking Sustainability*; Water Resources Research Center. University of Arizona: Tucson, 1999.

(30) U.S. Census Bureau, 2002 economic census, Industry Series Report. http://www.census.gov/econ/census02/ (2009).

(31) Kelly, T. D.; Matos, G. R. Histori cal statistics for mineral and material commodities in the United States, U.S. Geological Survey. http://minerals.usgs.gov/ds/2005/140/#gennotes (2005).

(32) Kammerer, J. C. Largest Rivers in the United States, Open-File Report 87-242; U.S. Geological Interview, Department of the Interior: Washington, DC, 1990.

(33) BLS (Bureau of Labor Statistics), CPI inflation calculator. http://data.bls.gov/cgi-bin/cpicalc.pl (2009)

(34) Alcamo, J.; Döll P.; Henrichs T.; Kaspar; F. Lehner B; Rösch T.; Siebert, S. Global estimates of water withdrawals and availability under current and future "business-as-usual" conditions. *Hydrol. Sci. J.* **2003**, *48* (3).

(35) Cicas, G.; Hendrickson C. T.; Horvath A.; Matthews H. S. Development of a regional economic and environmental input-output model of the US economy, *Int. J. Life Cycle Assess.* **2007**, DOI: http://dx.doi.org/10.1065/lca2007.04.318.

(36) Index Mundi, Commodity prices for sugar, http://www.indexmundi.com/commodities/?commodity=sugar&months=120 (2009).

ES903147K