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PUBLIC PERCEPTION OF DESALINATED PRODUCED WATER FROM OIL AND GAS FIELD OPERATIONS: A REPLICATION*

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ABSTRACT

This study is a replication of Theodori et al.'s (2009) research on public perception of desalinated produced water from oil and gas field operations. The data used in this paper were collected in twelve Texas counties. Overall, the findings of this investigation paralleled those uncovered in Theodori et al.'s original exploration. Our data reveal that small percentages of respondents are extremely familiar with the process of desalination and extremely confident that desalinated water could meet human drinking water quality and purity standards. Our data also indicate that respondents are more favorably disposed toward the use of desalinated water for purposes where the probability of human or animal ingestion is lessened. Lastly, our data show that individuals with higher levels of familiarity with the process of desalination were more likely than those with lower levels of familiarity to agree that desalinated water from oil and gas field operations could safely be used for each of nine proposed purposes. Possible implications of these findings are advanced.

Produced water refers to the water present in underground hydrocarbon-bearing formations brought to the surface during crude oil or natural gas production. Variations in the volume of produced water, as well as its physical and chemical composition, are attributable to many factors, including "the geographic location of the field, the geologic formation, the type of hydrocarbon produced, and the lifetime of a reservoir" (Clark and Veil 2009:13). Worldwide, oil and gas

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exploration and production operations are estimated to generate more than 200 million barrels (bbl) of produced water per day (Burnett 2007; Khatib and Verbeek 2003).[1] Produced water volume annual estimates for onshore oil and gas wells in the United States for the years 1985, 1995, and 2002 were 21 billion bbl, 18 billion bbl, and 14 billion bbl, respectively (API 2007; Clark and Veil 2009; Veil et al. 2004). According to Clark and Veil (2009), the estimated total volume of produced water in 2007 from U.S. onshore and offshore oil and gas production operations was about 21 billion bbl.[2] That year, the approximately one million actively producing oil and gas wells in the United States generated, on average, 57.4 million bbl of produced water per day (Clark and Veil 2009).

Undoubtedly, energy exploration and production activities, both onshore and offshore, generate copious amounts of produced water. The management and disposal of such large quantities of produced water, "the largest by-product or waste stream associated with oil and gas exploration and production" (Clark and Veil 2009:7), constitute a substantial expense to the energy industry (Clark and Veil 2009; Puder and Veil 2006; Theodori, Fox, and Burnett 2006; Veil et al. 2004). Furthermore, the management and disposal of such large produced water volumes present serious concerns for energy producers, state and federal regulatory agencies, non-governmental organizations, environmental groups, private landowners, and the public (Theodori et al. 2006, 2009). Presently, energy producers use several methods to manage and dispose of produced water. For offshore production activities, the produced water is generally discharged into the ocean after treatment. Clark and Veil (2009) noted that more than 91 percent of U.S. offshore produced water was disposed of by ocean discharge in 2007. For onshore production activities, produced water management and disposal methods typically include: surface discharge, underground injection for disposal, underground injection for increasing oil recovery, evaporation, offsite commercial disposal, and beneficial reuse (Clark and Veil 2009). In 2007, the vast majority of produced water generated in the United States (95.2 percent) was managed and disposed of through underground injection, either for enhanced recovery purposes (55.4 percent) or strictly for disposal (38.9 percent). About 700,000,000 bbl (4.4

[1]One bbl equals 42 U.S. gallons or 0.16 m^3.

[2]According to Clark and Veil (2009), more than 20 billion bbl of the 20,995,174,000 bbl of produced water generated in the United States in 2007 resulted from state and federal onshore oil and gas production. More than 700 million bbl of produced water were generated from federal offshore oil and gas activities and tribal land production.

percent of the total reported volume) was managed through surface discharges. The remaining produced water volume (< 0.06 percent) was managed through evaporation ponds, offsite commercial disposal, and beneficial reuse (Clark and Veil 2009).

Technologies that remove contaminants and dissolved salts from water produced in oil and gas field operations currently exist and continue to be refined. These water treatment technologies clean and purify the produced water, ultimately creating a beneficial freshwater resource. However, as reflected in Clark and Veil's (2009) report, the treatment of produced water for beneficial reuse has not been adopted and diffused as a noteworthy nationwide practice. Failed legislation introduced in the U.S. House of Representatives by Congressman Ralph Hall (R-TX) in 2007, H.R. Bill 2339 (U.S. Congress 2007), and reintroduced in 2009 as H.R. Bill 469 (U.S. Congress 2009), may have accelerated the research and development of technologies to treat and beneficially reuse produced water.

Researchers have speculated that several economic, regulatory, and social impediments must be addressed before widespread adoption and diffusion of produced water treatment technology for beneficial reuse occurs (Stewart 2006; Theodori et al. 2006, 2009). Included among the hypothesized impediments, as indicated by Theodori et al. (2009), are: the lack of market mechanisms or incentives for oil and gas operators to treat water and make it available as a commodity; current state and federal regulations that typically classify produced water as waste material, not as a by-product to be treated, recycled, and reused; and speculation about whether or not community leaders and members of the public are even aware of produced water treatment technology and the potential benefits. Two other potential barriers identified by Veil (2007) during his testimony to Congress in 2007 are: the concern by oil and gas companies' legal staff that giving and/or selling treated produced water to end users could result in future liability to the company; and, water rights issues associated with produced water before and after treatment.

Building upon such suppositions, Theodori et al. (2009) used data collected in 2006 in two north-central Texas counties to empirically explore issues associated with public perception of desalinated produced water. The researchers found that small percentages of the sampled respondents were extremely familiar with the process of desalination and extremely confident that desalinated produced water could meet human drinking water quality and purity standards. Their findings also revealed that individuals were more favorably disposed toward the use of desalinated produced water for purposes where the probability of human or animal ingestion is lessened. Lastly, their data showed that respondents who were more familiar with desalination technology were more likely than those who were less familiar to assert that desalinated oil and gas field produced water could safely be used for selected purposes.

Currently, engineers and scientists are investigating and disseminating information on selected technical, economic, and environmental issues and problems associated with beneficial reuse applications of treated produced water (Burnett 2007; Cath 2009; Dahm 2009; Debroux and Taffler 2009; Drewes et al. 2009; Johnson et al. 2008; Hancock 2009; Kanagy et al. 2008a, 2008b; Veil 2009; Xu 2009). These technical, economic, and environmental issues and problems pose difficult challenges for engineers and scientists to overcome. Equally demanding, and possibly more taxing, is finding solutions to the social concerns impeding the acceptance and use of treated produced water. To the best of our knowledge, no published sociological research other than the Theodori et al. (2009) study has been directed toward understanding public perception and acceptance of desalinated produced water. In the present paper we replicate Theodori et al.'s (2009) analyses. Here, like Theodori et al. (2009), we investigated the public's (a) level of familiarity with the process of desalination, (b) level of agreement that desalinated produced water could safely be used for selected purposes, and (c) level of confidence that desalinated water could meet human drinking water quality and purity standards. Also, as did Theodori et al. (2009), we examined the association between level of familiarity with the process of desalination and the proposed potential uses of desalinated produced water.

DATA

The data used for this paper were drawn from a 2008 study that focused on energy resources and natural environments in Texas (Theodori and Lyke-Ho-Gland 2008). Study sites for the larger project were purposely selected using region- and county-level data available from Texas Parks and Wildlife Department, the United States Census of Population and Housing, and the Railroad Commission of Texas. First, three ecological regions were selected to represent coastal wetlands, hardwood forests, and desert ecosystems using regions defined by Texas Parks and Wildlife Department. Next, using U.S. Census and Railroad Commission of Texas data, all counties in the regions were classified with respect to metropolitan and nonmetropolitan status and number of oil and gas wells. Four types of counties were identified: (1) counties in metropolitan or micropolitan statistical areas with many wells; (2) nonmetropolitan counties with many wells; (3) counties in metropolitan or micropolitan statistical areas with a few wells; and, (4) nonmetropolitan counties with a few wells. One county of each type was selected in each of the three ecological regions. In the coastal wetlands region, the counties of Brazoria, Refugio, Aransas, and Colorado were selected. In the hardwood forest region, the counties of Nacogdoches, Panola, Angelina, and Trinity were selected. In the desert region, the counties of Pecos, Reeves, El Paso, and Brewster were selected.

Following a modified total design method (Dillman 2000), data were gathered using mail survey techniques. During the spring of 2008, a survey questionnaire was mailed to a randomly selected sample of 5,948 households drawn from the twelve counties. A cover letter explaining the purpose of the study and an addressed postage-paid return envelope accompanied the questionnaire. The cover letter stated that the questionnaire was to be completed by the adult in the household who most recently celebrated his or her birthday. The survey instrument, organized as a self-completion booklet, contained 46 questions and required approximately 40 minutes to complete. After the initial survey mail-out and two follow-up mailings, a 21 percent response rate was achieved. This resulted in 1,228 completed questionnaires across the twelve counties.

MEASUREMENT OF VARIABLES

Measuring Familiarity with the Process of Desalination

Familiarity with the process of desalination was assessed using a single survey item that, after reverse coding, ranged from 1 (extremely unfamiliar) to 7 (extremely familiar).

Measuring Potential Uses of Desalinated Water

Potential uses of desalinated water were evaluated with a list of nine practices. Respondents were asked whether they believed that desalinated water from gas and oil field operations could safely be used for (1) re-use by gas and oil industry operators, (2) industrial use (e.g., manufacturing), (3) irrigation of farmland and/or rangeland, (4) municipal uses (e.g., watering golf courses and city parks), (5) watering of livestock, (6) home irrigation purposes (e.g., watering lawns and shrubs), (7) maintenance of stream flows/reservoir levels, (8) aquifer recharge, and (9) people's drinking water. Each potential usage was dummy coded (1 = yes).

Measuring Confidence that Desalinated Water Could Meet Human Drinking Water Standards

The respondents' confidence that desalinated water from gas and oil field operations could meet human drinking water quality and purity standards was assessed using a single survey item that ranged from 1 (not at all confident) to 7 (extremely confident). The wording of this survey item and each of the aforementioned items was identical to those asked by Theodori et al. (2009).

ANALYSES[3]

Following Theodori et al. (2009), we used descriptive statistics to examine respondents' level of familiarity with the process of desalination, their level of agreement that desalinated water from oil and gas field operations could safely be used for selected purposes, and their level of confidence that such desalinated water could meet human drinking water quality and purity standards. We then used bivariate and multivariate logistic regression techniques to empirically examine the association between level of familiarity with the process of desalination and the perceived safe potential uses of desalinated water.

As shown in Figure 1, approximately 18 percent of respondents reported being extremely unfamiliar with the process of desalination. Conversely, 5.5 percent of respondents, or roughly one-twentieth of the sample, indicated that they were extremely familiar with the desalination process. The mean level of familiarity with the process of desalination was 3.64 (SD = 1.81). These findings were similar to those reported by Theodori et al. (2009). In their study, the authors found that 23 percent of respondents were extremely unfamiliar, while 4 percent of respondents were extremely familiar. Their mean level of familiarity was slightly lower at 3.37 (SD = 1.81).

Despite their level of familiarity with desalination technology, an overwhelming majority (94 percent) believed re-use by gas and oil industry operators to be the safest potential use (Table 1). More than 9 in 10 respondents (93 percent) believed that desalinated water from oil and gas field operations could safely be used for industrial use (e.g., manufacturing), while 8 in 10 respondents (80 percent) agreed that such water could safely be used for municipal purposes (e.g., watering golf courses and city parks). About 3 in 4 respondents (78 percent) reported that desalinated produced water could safely be used for home irrigation purposes (e.g.,

[3] Cases with missing data on any of the variables used in the analyses were excluded. Hence, a listwise deletion reduced the sample to 899 cases.

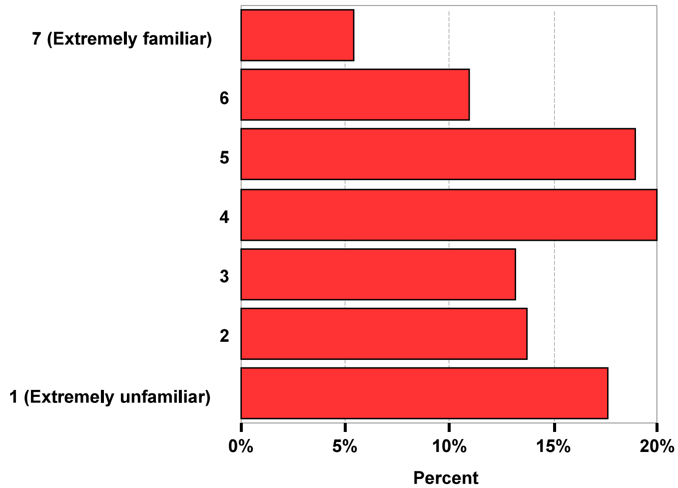

FIGURE 1. LEVEL OF FAMILIARITY WITH THE PROCESS OF DESALINATION

TABLE 1. DESCRIPTIVE STATISTICS FOR PERCEIVED SAFE POTENTIAL USES OF OIL AND GAS FIELD DESALINATED WATER

WAYS DESALINATED WATER MIGHT SAFELY BE USED:	YES	NO
Re-use by gas and oil industry operators.	94%	06%
Industrial use (e.g., manufacturing).	93%	07%
Municipal uses (e.g., watering golf courses and city parks).	80%	20%
Home irrigation purposes (e.g., watering lawns and shrubs)	78%	23%
Irrigation of farmland and/or rangeland................................	67%	33%
Maintenance of stream flows/reservoir levels.	51%	49%
Watering of livestock.	46%	54%
Aquifer recharge.	44%	56%
People's drinking water.	30%	70%

watering lawns and shrubs), while approximately 2 in 3 respondents (67 percent) proposed that such water could safely be used to irrigate farmland and/or rangeland. Roughly one half the respondents (51 percent) believed that desalinated water might be usable for maintaining stream flows and/or reservoir levels. Approximately 46 percent and 44 percent, respectively, agreed that watering of livestock and aquifer recharge could be safely accomplished with the use of desalinated water. Lastly, slightly less than one third of the respondents believed that desalinated produced water could safely be used by human as potable water.

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While the percentages of respondents who agreed that desalinated produced water could safely be used for the nine selected purposes differed slightly between this study and Theodori et al.'s (2009), the overall pattern of responses was the same. Re-use by gas and oil industry operators was viewed as the safest potential use of desalinated water, followed by industrial use, municipal uses, home irrigation purposes, irrigation of farmland and/or rangeland, maintenance of stream flow/reservoir levels, watering of livestock, aquifer recharge, and, finally, people's drinking water. Despite respondents' level of familiarity with desalination technology, as the potential for animal and human ingestion increases, the likelihood of concurrence that desalinated water could safely be used for such purposes decreased.

We explored the associations between level of familiarity with the process of desalination and the perceived safe potential uses of desalinated produced water using bivariate and multivariate logistic regression techniques. As in Theodori et al.'s (2009) study, gender and level of education were included in the multivariate models as control variables. As shown in Table 2, the bivariate relationships between level of familiarity with the process of desalination and each of the nine safe possible uses were positive and statistically significant (at the 0.01 level). This revealed that individuals with higher levels of familiarity with the process of

TABLE 2. LOGISTIC REGRESSION FOR PERCEIVED SAFE POTENTIAL USES OF OIL AND GAS FIELD DESALINATED WATER ON LEVEL OF FAMILIARITY WITH THE PROCESS OF DESALINATION

WAYS DESALINATED WATER COULD SAFELY BE USED:	ODDS RATIOS	
	BIVARIATE	MULTIVARIATE[a]
Re-use by gas and oil industry operators.	1.42***	1.37***
Industrial use (e.g., manufacturing).	1.41***	1.36***
Municipal uses (e.g., watering golf courses and city parks).	1.15**	1.14**
Home irrigation purposes (e.g., watering lawns and shrubs).	1.15**	1.14**
Irrigation of farmland and/or rangeland.	1.20***	1.19***
Maintenance of stream flows/reservoir levels.	1.15***	1.15***
Watering of livestock.	1.20***	1.20***
Aquifer recharge.	1.13**	1.12**
People's drinking water.	1.16***	1.15**

NOTES: [a]Odds ratios computed controlling for gender and education; $^{**}p \le 0.01$; $^{***}p \le 0.001$.

desalination were more likely than those with lower levels of familiarity to agree that desalinated water from oil and gas field operations could safely be used for each of the potential purposes. The multivariate results indicated that the addition of the control factors had very little effect on the nature or significance levels of the odds ratios for the familiarity with the process of desalination variable.

As shown in Figure 2, roughly one in five respondents (19 percent) reported being not at all confident that desalinated water from oil and gas field operations could meet human drinking water quality and purity standards. Conversely, about one out of every ten respondents (9 percent) believed that it could meet potable water standards. The mean level of confidence was 3.55 (SD = 1.92). Here, the optimism that desalinated produced water could meet quality and purity criteria was slightly greater than that found by Theodori et al. (2009). Theodori et al. (2009) indicated that 35 percent of their respondents reported not being at all confident that desalinated water could meet human drinking water quality and purity standards, while 5 percent believed it could measure up. Their mean level of confidence was 0.78 points lower (2.77; SD = 1.79).

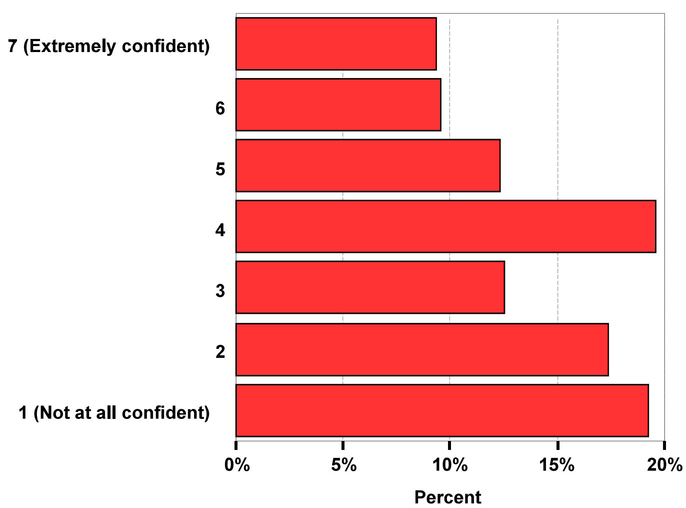

FIGURE 3. LEVEL OF CONFIDENCE THAT DESALINATED WATER FROM OIL AND GAS FIELD OPERATIONS COULD MEET HUMAN DRINKING WATER QUALITY AND PURITY STANDARDS

CONCLUDING COMMENTS

Oil and gas exploration and production operations worldwide, both onshore and offshore, generate more than 200 million barrels of produced water each day (Burnett 2007; Khatib and Verbeek 2003). Energy producers use several methods to manage and dispose of these produced water volumes. These include: discharge; underground injection for disposal; underground injection for increasing oil recovery; evaporation; offsite commercial disposal; and, beneficial reuse. The latter of these methods – beneficial reuse – is a potentially valuable yet infrequently utilized management practice (Clark and Veil 2009). Before widespread adoption and diffusion of beneficial reuse of produced water can successfully occur, several economic, legal, regulatory, and social impediments will undoubtedly need to be addressed. In the present study, which is a replication of Theodori et al.'s (2009) original research on public perception of desalinated water from oil and gas field operations, perceptual issues associated with produced water treatment technology and beneficial reuses of desalinated produced water were examined.

Overall, the results of this investigation paralleled Theodori et al.'s (2009) findings. As in the previous research, most respondents in our study were often more unfamiliar than familiar with the process of desalination technology. Our findings also suggested that respondents were more favorably disposed toward the use of desalinated produced water in instances where the probability of human or animal ingestion is lessened. While the percentages of respondents who agreed that desalinated produced water could safely be used for the nine selected purposes differed slightly between the two studies, the overall pattern of responses was the same. Similar to Theodori at al.'s (2009) findings, our results revealed that few respondents expressed complete confidence that desalinated produced water from oil and gas field operations could meet human drinking water quality and purity standards. Unlike Theodori et al. (2009), though, the logistic regression results in our study revealed that individuals with higher levels of familiarity with the process of desalination were more likely than those with lower levels of familiarity to agree that desalinated water from oil and gas field operations could safely be used for each of the nine proposed purposes.

In short, it appears that an understanding of desalination technology is associated with higher rates of perceived safe produced water reuses. This finding implies that public and/or private strategies to encourage extensive augmentation of desalination technology and beneficial reuse of produced water at local, regional, or national levels ultimately should be accompanied by educational and outreach programs aimed at increasing knowledge of the technology itself and of exactly what the specific technology can and cannot accomplish. Educational processes and outreach activities are extremely important. However, with the understanding that people converse and learn differently, it is imperative that educational and outreach professionals employ multiple methods of delivery when disseminating the scientific and technical information to various segments of the population. Concomitantly, building upon the lessons learned in the extant literature on the acceptability and use of reclaimed and/or recycled water (Hartley 2006; Marks 2006; Po, Kaercher, and Nancarrow 2004), educators and outreach professionals must engage and empower the public. Stakeholder involvement will be a crucial component in the attainment of public acceptance of desalinated produced water from oil and gas field operations. Lastly, members of the public should be encouraged to communicate their hopes, fears, and/or anxieties associated with desalination technology and the potentially positive aspects and negative consequences of treated produced water reuse. Open and honest communication from all parties will initiate, build, and maintain credibility and trust in the process and reduce the spread of rumors and inaccuracies with respect to what desalination technology can and cannot achieve.

AUTHOR BIOGRAPHY

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Mona Avalos is the Air & Energy/Public Health Program Assistant at the Natural Resources Defense Council. She has worked for the Union of Concerned Scientists and with Public Citizen in Austin, TX. Ms. Avalos recently earned a Master of Arts degree in Sociology with a concentration in community and natural resources from Sam Houston State University. She holds a Bachelor of Science degree in Biology from this university.

David B. Burnett is Director of Technology for the Global Petroleum Research Institute (GPRI) and Research Project Coordinator for the Department of Petroleum Engineering at Texas A&M University. He served as a managing partner for the U.S. Department of Energy's project DE-FC26-05NT42658 *Field Testing of Environmentally Friendly Drilling Systems*, a partnership among university,

industry, governmental, and non-governmental organizations dedicated to reducing the impact of oil and gas operations in environmentally sensitive areas. Mr. Burnett leads a research team developing advanced membrane filtration technology to reduce waste water and flowback fracturing fluid volumes at rig sites. He received the 2006 Hearst Energy Award for Technology in the oil industry and his research team also won Gulf Publishing Company's 2008 *World Oil* Health Safety Environment/Sustainable Development Award.

John A. Veil spent more than 20 years as Manager of the Water Policy Program for Argonne National Laboratory, where he evaluated and analyzed technologies and regulatory issues relating to the oil and gas and electric power industries. In early 2011, Dr. Veil retired from Argonne and established a consulting practice, Veil Environmental, LLC. He is widely known for his work relating to management of produced water and drilling wastes from oil and gas wells. He has made presentations at many conferences around the world and is the lead developer for the Produced Water Management Information System and the Drilling Waste Management Information System websites.

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