Boosting direct potable reuse: measures to be taken to help shorten the knowledge gaps and uncertainties surrounding this technology

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Abstract

Water scarcity will be one of the main problems to be faced by the world in the 21st century, with projections of up to 40% global water deficit scenario by 2030. Direct potable reuse is one possible tool to address this problem, but big knowledge gaps, such as lack of specific legislation, water quality concerns, public acceptance and economic feasibility prevent it to get broad implementation. In this work, authors address each of this knowledge gaps and estimate project is economically feasible if water price can be $2.54/100 cubic feet with a net production of 17 million gallons per day.

Introduction

Fresh water, although essential for the development of any nation, is an extremely limited resource. From all existing water in our planet, 4% is freshwater, and only 0.01% accounts for readily available water in rivers and lakes, which are the most common sources of freshwater supply for communities (Berner, 2017).

Too much freshwater is wasted, polluted, unsustainably managed or unevenly distributed, raising concerns for water avaliability as of today; situation will only deteriorate if world´s population keeps increasing, to the point it reaches estimated 9.73 billion by 2050 (United Nations, 2015), a growth of 32%. As a result, water scenario and possible widespread water scarcity in the coming decades has become a concern. United Nations considers water scarcity one of the main problems to be faced by the world in the 21st century, projecting a 40% global water deficit under the business-as-usual (BAU) scenario by 2030. (WWAP, 2015).

The most vulnerable communities are the ones using single sources of water and that are climate dependant, because of concerns of climate change and how will hydrological cycles be affected by it. Therefore, these communities are expected to be looking progressively for alternative sources of water supply, as a way to increase water security. Some of the alternative sources available are desalination (of seawater in coastal areas or of brackish water), rainfall harvesting and water reuse, both direct and indirect.

Desalination of seawater or brackish water is well developed in some countries and has been growing near exponentially (Dolnicar & Schafer, 2009). Meanwhile, reuse has also been getting its share, with over 3,300 projects of non-potable reuses applications worlwide as of 2005 (Rodriguez et al, 2009). Water reuse has been traditionally limited to non-potable reuse; however, with the advancedment of technology it is possible today to obtain potable water, from virtually any sources, including from water that has already been used.

Potable reuse occurs as direct potable reuse (DPR) and indirect potable reuse (IPR), where IPR uses an enviromental buffer as intermidiate and DPR does not. In DPR, water, normally originated as municipal wastewater (sewage generated by the community), undergoes advanced treatment and then is used for human consumption, as schematized in figure 1. General technology used on recent DPR projects is presented in figure 1.

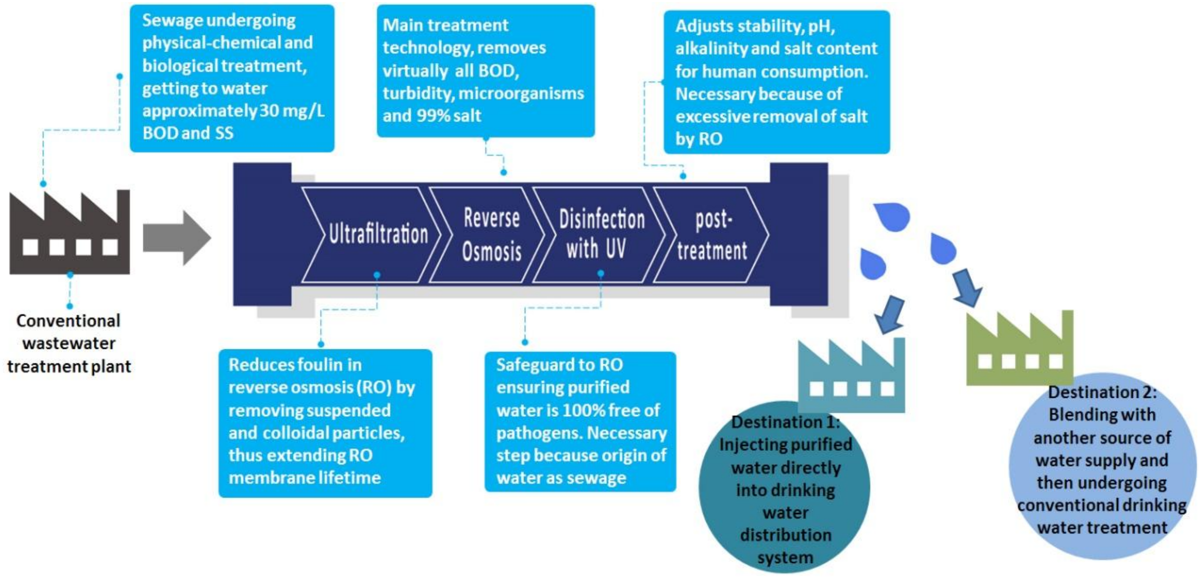

Figure 1: a scheme of direct potable reuse. Source: the authors

DPR was first introduced in Windhoek, Namibia, in 1968 and has been operating successfully ever since, but nonetheless, DPR plants are still a novelty, and therefore many open questions remain. With big knowledge gap, it is no surprise that DPR projects have not so far gotten broad implementation, despite its promise to help addressing water problems.

The purpose of this work is to present measures to be taken by water supply utilities wishing to implement a DPR Project but uncertain of how to proceed. These are measures to be taken into consideration during the initial planning phase, after a preliminary feasibility study has pointed DPR is the best option available for a given location (against previously mentioned options), for utilities wanting to anticipate problems that can arise when doing a DPR Project and/or in doubt of how to begin due to gaps in knowledge and uncertainty. These measures are presented in figure 2, as well as an estimation made by authors of how much time each one will need. They will be further discussed in coming sections.

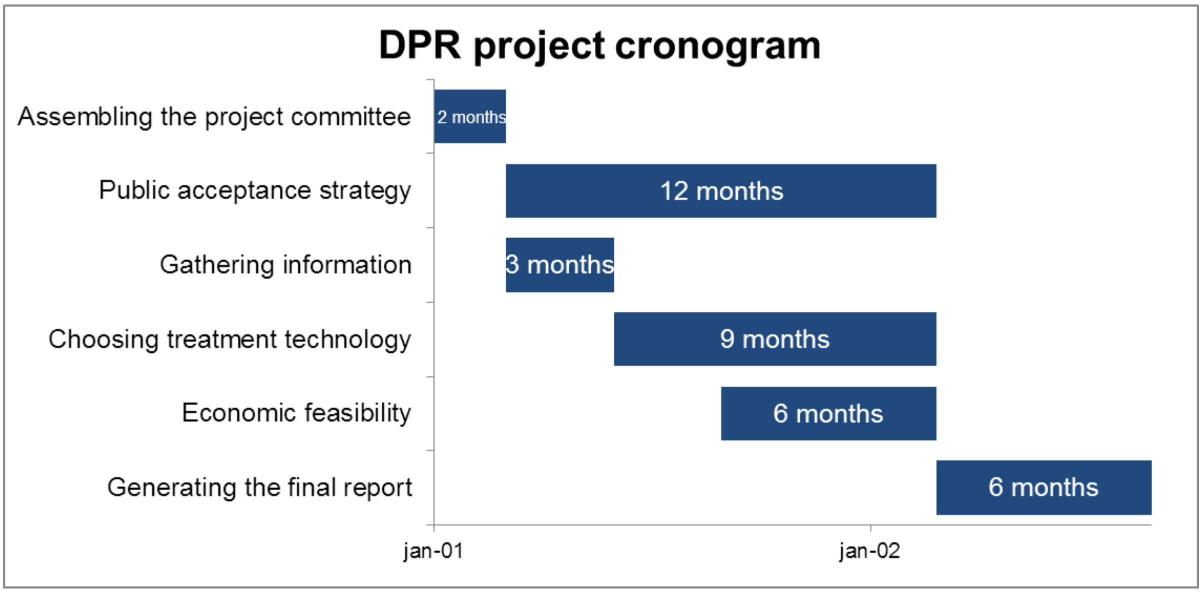

Figure 2: measures to be taken by water utilities. Source: the authors

Methodology

This work was written from extensive research on references. To aid the research, the authors used the following platfforms: SCOPUS, Science Direct, Google Scholar, Periódicos CAPES and New York Institute of Technology (where the main work was developed) Library Resources.

In addition, for the item "Evaluating the economic feasibility", the authors used the net-present value (NPV) tool, as presented below:

$$NPV = -investment + \sum_{t=1}^{t=n} \frac{Profit}{(1+k)^t} \quad (1)$$

Where t=project lifetime (assumed 10 years) and k is the minimum annual return rate for the Project (assumed 10%[1]).

In equation 1, investment is represented by the capital costs, i.e., construction cost for the DPR plant. The procedure to calculate construction cost is to do preliminary design of the main equipment of the DPR [2](pumps, tanks and ultrafiltration and

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[1] The minimum return rate is the minimum rate that, when making an investment, the investor expects to get as return. Without further studies, authors assumed a 10% annual return rate, since a detailed financial investigation is out of scope of this work. Similarly, we assumed an inflation of 1% per year for the US.

[2] Preliminary design of plant requires extensive calculations that are too big to be presented in this study. These calculations comprise another work by same authors submitted but not yet published. In the scope of this work, we will use data imported

reverse osmosis systems) and use vendor quotes and/or book price correlations to estimate equipment and installation costs brough to value of 2015 dollars.

In equation 1, profit is represented by revenue – expenses[3]. Expenses are calculated considering consumption of electricity and chemicals during operation, as well as other expenses (labor, piloting, insurance) as oriented by an EPA Cost manual (EPA, 2005), brough to 2015 dollars.

Revenue is given by the price of purified water ($/gal) times the production of purified water per year (gal). We considered production of purified water for a design flow of 25 million gallors per day (MGD) for the plant, and the following purified water prices:

- $1.02/100 cubic feet (hcf), which is the real price of water billed in the city of Sacramento, California, as of 2017 (Sacramento Suburban Water District, 2017). This city, the capital of state, was chosen as representative not only of California state but any city facing water shortages on a constant basis, and therefore interested in developing alternative water supple sources.
- $3.81/hcf, real price of water billed in New York City as of 2017 (New York City Water Board, 2017). This city was chosen because it was where this work was mainly developed.
- Intermediate values of $1.5/hcf and $2.5/hcf.

We adjusted both expenses and revenue for inflation considering 1% per year of inflation.

Where NPV was greater than zero, the project is considered economically feasible. However, in this study we sought not only positive NPV but high NPV, to account for the many uncertantities of this study, such as: not considering the cost of land for construction of DPR plant and royalties, not considering taxes, depreciation and amortization (see footnote 2) and the expected increase in cost of producing and operating the plant once a more detailed engineering study is done.

Results

1. Assembling the project committee

The first step is to organize the committee that will be responsible for conducting the next steps and generating the final report. The team should be composed of executive members of the public or private water utility, and can chose either to proceed internally or to delegate it to a third-party, independent consulting company. If internally, then proceed to create a commission of managers and technical personnel, which must have sanitary, chemical and civil engineers, microbiologists, chemists, and so on in its staff. If delegating, the committee must ensure still have its

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from this other work, presented in table 3. This is also valid for calculations of operating costs.

[3] Rigourously speaking, the profit is the revenue generated by selling water to customers minus all O&M costs (here called expenses), depreciation, amortization, interest and taxes, but these calculations require a detailed study that is out of scope of this work. Therefore, we are using EBITDA (earnings before interest, taxes, depreciation and amortization) instead, where EBITDA = revenue – expenses.

own technicians able to issue opinions on the reports presented by the consulting company.
One good practice is to attend water management related congresses and conferences and to allocate some money on acquiring materials specifically published for DPR. The authors consider this step of assembling the "DPR committee" should take around 2 months.

2. Gathering information

The DPR commitee should first focus on gathering available and most up-to-date information, in its own country and worldwide, regarding DPR. Moreover, identifying legislation and regulatory requirements for potable water in the locality, water quality goals for potable water, water reuse already practiced in the surroundings, if any, and risk management practices. Risk management in this context can be understood as redundancy of equipment, providing a multi-barrier for contaminants, especially pathogens; robustness; equipment reliability, hability of handling process variations excpected in real life, and a rapid monitoring/alarm/automated control system that mitigates risk if something goes wrong.

Committee should list the most important and relevant open questions so they can be properly addressed in the course of the project (table 1 ilustrate some of them). If possible, get in touch with the managers of existing DPR plants for first-hand information.

Table 1: relevant open questions on DPR.

Relevant questions for DPR projects	*Course of action*	*Addressed in this work*
Absence of regulation referring specifically to direct potable reuse, or drinking water from a municipal wastewater source	Use current regulations for potable water applicable for the location of DPR plant.	Item 2.1
	Set their own requirements for operation	Item 2.2
Setting water quality goals for treated water	Use current water quality goals for potable (drinking) water	Item 2.1
Choosing technologies to be used in DPR plant	Use as basis technologies in use in existing or to be constructed plants.	Item 3.1
Confirming if technologies chosen comply with the water quality goals set and with risk management.	Conduct pilot tests	Item 3.2
Confirming the technologies chosen are enough for the chosen destination of purified water	Conduct pilot tests	Item 3.3
Confirming the technologies chosen are enough provide purified	Conduct pilot tests	Item 3.4

water with good taste		
Analyze if water produced for DPR can have a feasible price (similar to those already practiced)	Do basic economic evaluation of DPR plant using NPV economic analysis method.	Item 4
Proper way to handle public image of DPR and public acceptance	List public acceptance issues, and possible causes for it	Item 5.1
	Using considerations of item 5.2, list actions to improve public acceptance.	Item 5.2

2.1) Any plant designed to run a DPR project should comply with both legislation and water quality parameters required for potable water already practiced by the respective country. Water quality goals for drinking water can vary slightly depending on country, but have in common a demand of pH between 5-8, temperature around 25°C, no turbidity, odor or color, virtually no SS, conductivity below 500 mg/L and free of pathogens, which is achieved by disinfection with chlorine or ultraviolet (UV) light.

2.2) Maseeh et al (2015) reported that, in the absence of specific guidelines and regulation, the strategy adopted by the team behind the EL Paso purification facility, a DPR project that is being developed in the United States and predicted to be inaugurated in 2019, was to establish the following as goals:

-To meet all state primary and secondary drinking water standards;
-To make sure a multiple barrier to pathogens is provided;
-To do proper risk management.
This srategy could be adopted for coming DPR projects.

3. Choosing treatment technology

3.1) With the project goals in mind, DPR committee needs to choose the treatment technology to be used as advanced treatment, and make sure this technology is enough to comply with the water quality goals set in step 2 and with risk management. In this step, it is extremely useful to do extensive research on current DPR plants operating and take a close look at the technologies they are using.

As shown in figure 1, the technology most used today is, generically, a step of membrane technology (ultrafiltration and reverse osmosis) and a step of disinfection using ultraviolet (UV) light. This technology train was pioneered by Singapore's Public Water Agency (PUB) and is the choice of the two only operating DPR plants in the United States (US), named Big Springs and Wichita Falls, both located in Texas. Others existing technologies can be added to the process (advanced oxidation for example with hydrogen peroxide, granular activated carbon contactors, or chlorination), needing to be evaluated case-by-case.

PUB claims its reclaimed water has passed more than 150,000 scientific tests and is within World Health Organization requirements, (PUB WEBSITE, 2017), while both

Big Springs and Wichita Falls have been operating for 2 years without problems. However, it is important to keep in mind Singapore's plants itself do not practice DPR yet, but IPR.

All of recent DPR plants operating worldwide, including the ones in US, are in mode of destination 2 (see figure 1), so it is correct to say that, at the moment, no DPR plant in the world that uses the combo membrane+UV light technology gets purified water to destination 1. The only example of destination 1 is also the oldest one, DPR plant operating in Windhoek, Namibia, but the technologies used there are different, since membrane technology was not viable in 1968. For more information on Windhoek plant, see Lahnsteiner & Lempert (2007).

3.2) An important consideration to be made is the need of piloting tests. It is recommended that the committee overlooks pilot tests done with the exact same technology train choosen, using same inlet water quality as expected in the full project, for at least 6 months, while conducting a battery of chemical and biological analyses. Parameters can be varied to simulate real-life variations. This is also risk management – to assess if the multi-barrier is enough to handle the variations. By the end of the pilot tests, a useful database of real-life scenario will be created, so the committee can assess by their own the quality of produced purified water.

If tests are negative for all pathogens, comproving the good quality of water, then the utility/DPR committee will have a solid basis to justify the safety of the DPR project and proceed. Or else, if for any given condition water is not safe, adjustment can be done before the project proceeds, for example, adding another technology as an extra barrier to contaminants.

3.3) Choice of technology train depends a lot on the final destination of purified water, whether 1 or 2 (see figure 1). If purified water is to be introduced directly in the distribution system, it should be chlorinated, not for disinfection exactly but to avoid biological contamination in the distribution system (residual chlorine). However, if purified water is to be blended with other sources of untreated water and then undergoes drinking water treatment, it doesn't have to be chlorinated inside the DPR plant because it will occur by the end of drinking treatment.

From an engineering point, makes more sense introducing purified water directly to the drinking water distribution because purified water is already drinkable, being a waste to blend it with raw surface water, which in reality contaminates it, to treat everything again. If choosing strategy 2, the inlet flow will be high and the conventional drinking water treatment facility will have to be designed to be much bigger than in scenario 1.

Nevertheless, from a risk management point of view, strategy 2 is safer. If water goes straight to distribution, it is critical to think in what to do in case water goes out of specification for whatever reason, and whether there would be enough time for detection before water gets to the distribution. One option would be to keep a big storage tank to provide some response time before water gets into the distribution system. This problem justifies why, in despite of its higher cost, strategy 2 has been the choice of all DPR plants recently.

3.4) Another important consideration is whether the purified water produced by the plant has a good taste. It is well established that reverse osmosis can produce water of very high quality, but few address how is the palatability of this permeate water. Duranceau (2008) and many others state that water permeated from reverse osmosis has so low TDS value that is unpalatable, corrosive and unhealthy, therefore requiring post-treatment. This is required not only for potable uses, but to all uses, since it is always necessary to increase the stability of permeate water. While a step of pH/alkalinity adjustment corrects the stability problems and increases TDS, there is a big gap of studies assessing the actual "taste" of the post-treated water with real consumers. This issue can also be addressed during pilot tests; once water quality regarding public health is ensured, volunteers can drink and assess its "taste" and "odor" against conventional water.

4. Economic feasibility

Table 2 lists briefly considerations made to calculate NPV, which are extensively presented in another study, while table 3 summarized the results of this study. We assumed a design flow of 25 million gallons per day (MGD), with net production of purified water of 17 MGD because recovery of membrane systems is not 100%. Costs are calculated in U$ dollars for the United States, baseline 2015, adjusted for inflation.

Table 2: considerations for NPV method.

Item	*Considerations for calculations*	*References*
Investment (year 0)	Direct costs: equipment (membrane for ultrafiltration and reverse osmosis and its vessels, UV reactor and UV lamps) cost by vendor quote/price correlations, and its respective mounting, valves, instrumentation, electrical, civil, painting calculated a % of equipment price. Indirect costs: permitting, pilot tests, operator training, insurance	EPA, 2005; Baker et al, 2014; Wilbert el al, 1997; Towler & Sinnott, 2013; Walas, 1991; Hammer et l, 2012; vendor quotes.
Expenses (year basis)	Variable: electricity (for membranes pumps) and chemicals consumption (for membrane cleaning and alkalinity adjustment). Electricity cost considered $0.1049/kWh. Fixed: operating labor cost, management/administrative costs, maintenance, monitoring	EPA, 2005, vendor quotes. Prices for electricity considered for the city of Sacramento, California as of 2015.

Revenue (year basis)	1) \$0.0014/gal x 17 MGD x 365D/year 2) \$0.0021/gal x 17 MGD x 365D/year 3) \$0.0034/gal x 17 MGD x 365D/year 4) \$0.0052/gal x 17 MGD x 365D/year	Sacramento Suburban Water District, 2017 New York City Water Board, 2017

Table 3: results to be used as input on NPV.

Calculation	*Total calculated in US dollars*
Investment	45,856,386
Expenses	7,003,319
Revenue	1) 8,687,000 2) 13,030,500 3) 21,090,000 4) 32,266,000

Considering the values of table 3, we adjusted revenue and expenses from year 2 to 10 based on 1% inflation and used equation 1 to calculate NPV for the four values of revenue. The values found for NPV were: 1) -35,115,991 2) -7,408,305 3) 44,004,172 and 4) 115,297,161, which gives project feasible for water price of at least \$0.0034/gal or \$2.54/hcf. Water rates currently practiced in the city of Sacramento are much lower than this, at \$1,02/hcf, while water prices for New York City are already considerably higher than this, at 3,81/hcf.

It is important to mention that water prices for public supply are not a traditional selling product, but rather a question of most basic need and of public health. Therefore, faced with uncertain water demands for the future or with scarcity, and presented with the possibility of increasing drinking water supplies and thus water security, community, understood here broadly as not only people but also farmers and industry, should be willing to pay more rather than facing more and more frequent water rationing. Water rationing is prejudicial not only for the quality of life of populations but also for economic development, since it creates obstacles for the full growth of the economy. As a result, we consider a purified water price \$2,54/hcf feasible.

5. Public acceptance strategy

Public opinion tends to be favorable to non-potable reuse, because the perception of water as valuable, important, a “treasure” is growing and tend to be well accepted. However things get different when it comes to accept reclaimed water for human consumption. Many experts recognize it is one of the biggest, perhaps the biggest, obstacle for DPR widespread implementation (Chan, 2014; Hurlimann & Dolcar, 2010; Dolnicar & Schafer, 2009; Marks, 2006; Cain, 2011).

5.1) Many aspects can be discussed regarding public. Dolnicar & Schafer (2009), for example, present some issues to be considered, which are given in table 4.

Considering these authors' approach, this work presents a summarization to answer these questions, as presented in table 4.

Table 4: summarize of public acceptance issues.

Public acceptance issues	*Factors affecting*
1.Main concerns of the public	1.1."The yuck factor" – an natural, instinctive resistance to everything associated with sewage, that experts attribute to instint that anything related to feces is harmful. 1.2.Public's lack of trust in the institutions responsible for delivering the project: valid everywhere, but expected to vary depending on the country, on the level of education and access of information, political and economic moment, and so on.
2.Public perception of water supply and recycled water	2.1.The way DPR project is presented in media: Media, especially social networks, has a great impact in the modern life as opinion makers, and the way DPR will be presented will heavily affect its acceptance. Headlines with terms like "toilet to tap", "sewage beverage" and photos showing water in the toilet next to lines like "your next source of water may be this" have happened before and will quickly denigrate the image of the project. 2.2.Common perception that water is everywhere: this will depend heavily on the country; some of them can have a "culture of abundance of water" that is harmful, for reclaimed water projects will be deemed unnecessary.
3.Amount of good knowledge on the theme	3.1.Public's lack of trust that environmental technologies: perception that environmental technologies can be good, but not as good as "nature" to ensure quality for human consumption, then, "to guarantee", the reuse of water should be maintained with minimal contact with humans. Chan (2014) and Marks (2006) mention several opinion polls that concluded that the level of water reuse acceptance increases as declines the level of contact with the reuse water.
4.Likehood of a resident to accept DPR	4.1.In descrescent order: education, age, knowledge on the theme, income and gender are the main influencing factors according to Dolnicar & Schafer (2009).

5.2) Considering the factors listed in table 4, the authors propose the following measures to help easing public image of a DPR project within a community:

- Ensure there will be transparency and good information available during the entire process, with special attention to the early stages of the project; timing is crucial. Marks (2006) mentions there is an historic of overall lack of transparency at the earliest planning stages, while Hurlimann & Dolnicar (2010) presented a study case in Australia where bad publicity at an early stage was proven decisive in getting an IPR Project blocked by the community. DPR committee should ensure project information, status and issues do not leak to the press before the project is consolidated at least to the point of being able to provide basic information with clarity for laypeople, and has a spokesperson designed to present it to press.

- Ensure good quality and favorable information is not only available but also visible. Keep in mind the general public does not have access to technical discussions and bulletins, informing itself by social networks and newspaper instead, and it is up to the committee to guarantee a favorable view will be presented in such channels.

- Know who the target public is, in terms of scholarity, income and age, to be able to adapt the marketing strategy and to get to them. For example, older people will use more traditional media (TV and newspaper) and new people, social networks. In additiom, use language accordingly: drop labels such as direct reuse, reverse osmosis or ultraviolet light, which are not clear for a general audience, instead using terms such as purified water or advanced treated water. And don’t talk about “educating” people, which many resent, rather use “informing”, while always emphasizing the environmental sustainability gains of the project. (KATZ & TENNYSON, 2015)

- Allocate money on budget for marketing. On a guide for water projects, EPA references cite at least $50,000 as budget for public information (EPA, 2005), but considering the high investments that can be involved in DPR project, the authors consider justified to invest at least $100,000 on this sensitive matter, than can in fact block the entire project if not properly handled. Money could be used by the committee to hire a spokesperson, producing good marketing materials (videos, flyers, etc) and setting an online platform. Later, if DPR plant is constructed, it is a good practice to create a visitor center program.

6. Generating the final report

Having considered all aspects discussed so far, the committee will be able to make an in-depth assessment of feasibility of DPR Project as a whole, and thus should generate a final report comprising not only information gathered but also a final opinion on whether proceed with the project or not. If the answer is proceed, the next steps would be getting fund for the project and starting developing a more detailed engineering project.
When writing the report, the committee should make clear the limitations of the study (for example, in economic analysis), the sources of uncertainty and which open questions remain that were not addressed.

Conclusion

This work sought to present steps to be taken by water supply utilities wishing to implement an DPR Project but uncertain of how to proceed due to gaps in knowledge that arise from DPR being a novelty. The authors described six steps and highlighted as major issues the absence of regulation referring specifically to DPR, the need to set water quality goals for purified water, choosing the most suitable technologies, confirming they are enough to provide adequate water, economic feasibility of DPR and public acceptance. Throughout this work, each issue has been discussed and suggestions made on how to address then. DPR project was considered economically feasible as presents a positive NPV for a purified water price of $2.54/hcf or $0.0034/gal, for a net water production of 17 MGD, which is midway between a $1.02/hcf water price in Sacramento, California, and $3.81/hcf in New York City.

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References

Berner, E.K. (2017), Water Resources, *AcessScience encyclopedia*. Available from: doi.org/10.1036/1097-8542.801450 [acessed 24th january 2017]

Baker, R.W. (2004) Membrane Technology and Applications", textbook, 2nd edition, ed. John Wiley & Sons.

Cain, C.R. (2011) An analysis of direct potable water reuse acceptance in the United States: obstacles and opportunities. Available from: http://www.jhsph.edu/academics/degree-programs/master-of-public-health/curriculum/Charla%20Cain%20capstone%20paper%202011.pdf [accessed december 2015]

Chan, A. (2014), The Future of Direct Potable Reuse in California: Overcoming Public Acceptance Barriers. Available from: http://repository.usfca.edu/cgi/viewcontent.cgi?article=1101&context=capstone [accessed 14 november 2016]

Dolnicar, S., Schafer, A. (2009) Desalinated versus recycled water: Public perceptions and profiles of the accepters. *Journal of Environmental Management*. 90 (2), 888–900. Available from: doi:10.1016/j.jenvman.2008.02.003 [accessed 22 December 2016]

Duranceau, S.J. (2008) Desalination Post-Treatment Considerations. *AWWA Fall Conference*. Available from: http://fwrj.com/techarticles/1109%20FWRJ_tech1.pdf [accessed December 2015]

Environmental Protection Agency (2005), Technologies and Costs Document for the Final Long Term 2 Enhanced Surface Water Treatment Rule and Final Stage 2 Disinfectants and Disinfection Byproducts Rule, EPA 815-R-05-013. Available from: https://nepis.epa.gov/Exe/ZyNET.exe/P100LZ09.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2000+Thru+2005&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFie

ldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C00thru05%5CTxt%5C00000034%5CP100LZ09.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL# [accessed november 2015]

Global Agriculture. (2017) Water. Available from: http://www.globalagriculture.org/report-topics/water.html [accessed 22th january 2017]

Hammer, M.J. (2012) Water and Wastewater Technology, Textbook, 7th edition, ed. Prentice Hall.

Hurlimann, A., Dolnicar, S. (2010) When Public Opposition Defeats Alternative Water Projects - the Case of Toowoomba, Australia. *Water Research*. 44 (1), 287-297. Available from: doi:10.1016/j.watres.2009.09.020 [accessed 13 november 2016]

Katz, S.M., Tennyson, P.A. (2015) Public outreach for potable reuse: bringing the public to a new level of acceptance. *Journal American Water Works Association*.107(11), 46-53. Available from: doi:10.5942/jawwa.2015.107.0160 [accessed november 2015]

Lahnsteiner, J., Lempert, G. (2007) Water management in Windhoek, Namibia. *Water Science and Technology*. 55 (1-2), 441-448. Available from: doi:10.2166/wst.2007.022, [accessed october 2016]

Marks, J.S. (2006) Taking the public seriously: the case of potable and non potable reuse. *Integrated Concepts in Water Recycling* .187(1), 137-147. Available from: doi:10.1016/j.desal.2005.04.074 [accessed 13 november 2016]

Maseeh, G.P, Russel, C.G., Villalobos, S.L., Balliew, J.E., Trejo, G. (2015) El Paso's Advanced water purification facility: a new direction in potable reuse. *Journal of American Water Works Association*. 107(11), 36-45. Available from: doi:10.5942/jawwa.2015.107.0168 [accessed november 2015]

New York City Water Board. (2017) "Water and Wastewater Rate Schedule". Available from: http://www.nyc.gov/html/nycwaterboard/pdf/rates/fy2016_rates.pdf [accessed 24 january 2017]

PUB, The National Water Agency. (2017) NEwater. Available from: https://www.pub.gov.sg/watersupply/fournationaltaps/newater [accessed 24th january 2017]

Rodriguez, C., Buynder, P., Lugg, R., Blair, P., Devine, B., Cook, A., Weinstein, P. (2009) Indirect Potable Reuse: A Sustainable Water Supply Alternative. I*nt. J. Environ. Res. Public Health*. *6*(3),1174-1203. Available from: doi:10.3390/ijerph6031174 [accessed january 19th, 2017]

Sacramento Suburban Water Districit. (2017) “Summary of Rates and Charges Frequently Asked Questions”. Available from: http://www.sswd.org/modules/showdocument.aspx?documentid=7847 [accessed 24 january 2017]

Towler, G., Sinnot, R. (2013) Chemical Engineering Design: principles, practice and economics of plant and process design, texbook, 2nd edition, ed. Elsevier

United Nations, Department of Economic and Social Affairs, Population Division. (2015) World Population Prospects: The 2015 Revision, World Population 2015 Wallchart. Available from: https://esa.un.org/unpd/wpp/Publications/ [acessed 22th january 2017]

Walas, S.M. (1991) Chemical Process Equipment, selection and design”, textbook, ed. Butterworth-Heinemman.

Water Reuse Foundation. (2015) Framework for direct potable reuse. Available from: https://watereuse.org/wp-content/uploads/2015/09/14-20.pdf [accessed 14 november 2016]

Wilbert, M., Leitz, F., Abart, E., Boeglki, B., Linton, K. (1998) The Desalting and Water Treatment Membrane Manual: A Guide to Membranes for Municipal Water Treatment - Water Treatment Technology Program Report No. 29”, textbook, 2nd edition, ed. US Department of the Interior.

World Business Council for Sustainable Development. (2005) Water Facts and Trends. Available from: http://www.unwater.org/downloads/Water_facts_and_trends.pdf [accessed 22th january 2017]

WWAP (United Nations World Water Assessment Programme). (2015) The United Nations World Water Development Report 2015: Water for a Sustainable World. Paris, UNESCO. Available from: http://unesdoc.unesco.org/images/0023/002318/231823E.pdf [accessed 24th january 2017]