Development of indirect potable reuse in impacted areas of the United States

H.P. Jansen*, M.K. Stenstrom and J. de Koning***

*Faculty of Civil Engineering and Geosciences, Department of Water Management, Delft University of Technology, The Netherlands (E-mail: *hrmjnsn@ucla.edu*)

**Department of Civil and Environmental Engineering, University of California Los Angeles, USA

Abstract This paper demonstrates the development of indirect potable reuse (IPR) in the United States. A legislative review and a survey of plants show that IPR is becoming an integral part of water reclamation. Public resistance is the limiting factor to its development while technology is not.

Keywords California; indirect potable reuse; institutional barriers; membranes; water reclamation

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Introduction

Water resources are in short supply in areas of the United States. Water supply is impacted by the increasing risk of periodic droughts and continuing development. In response to both needs, additional water supplies are being developed (Levine and Asano, 2004). Water reclamation is viewed as a new source of water and is being rapidly developed in many areas, particularly in Southern California, Arizona and Florida. In spite of the need for additional water and the promise of water reclamation, there are technical and institutional barriers that challenge its implementation.

In order to quantify the amount of reclamation and the problems associated with its development, a survey of both successful and failed projects in California, Arizona and Florida was performed. These three states were selected because of the need for reclamation due to arid conditions and rapid development and because of the existence of numerous early successful and unsuccessful projects. Affiliation with indirect potable reuse (IPR) was the main criterion for selecting projects. IPR is a method of reusing treated waters and wastewaters for potable use through at least one environmental barrier (Madireddi *et al.*, 1997) that serves to isolate, as well as protect, consumers. Examples of barriers include a groundwater basin or reservoir providing more than 1-year retention time. Projects involving IPR are much harder to implement because of the public's concern and there are many noteworthy examples.

A survey was conducted by collecting historical data on each plant as well as visiting the plant. Current records were obtained including assessments of their evolving water treatment technologies. Twenty-six projects were reviewed and 19 of the projects were visited. The relevant laws and regulations that governed the project were also reviewed. The various projects were categorised by size, technology, goals, successes and failures and relative costs.

Technological barriers were not a limiting factor. Institutional barriers and challenges such as public perception, local politics, risk communication and impacts of confusing or partially developed regulations were most often limiting. The most successful projects involved the public and other stakeholders before the conception of the project. Lower water reuse objectives (non-potable reuse (NPR)) were more easily implemented than

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higher use projects (IPR). No examples of successfully implemented direct potable reuse (DPR) were found in the US. In some cases, projects that began with IPR goals were converted to or augmented with lower use goals by displacing potable water with reclaimed water.

A review of the technologies of successful projects reveals a declining use of traditional water treatment technologies, such as granular media filtration, carbon adsorption, lime clarification, ammonia stripping and chlorination, and replacement with membrane-based technologies such as (submerged) micro filtration (MF), nanofiltration (NF), reverse osmosis (RO), disinfection with ultra violet (UV) light and advanced oxidation with hydrogen peroxide. A review of the controlling regulations, survey results and a discussion of the trends in regulations, technologies and reasons for success or failure of the major projects is also presented.

Background and methods

There are many definitions of water reuse and there are numerous examples of wastewater being discharged into waters that are used as drinking water resources, thus resulting in unplanned IPR. This unplanned reuse seems to be well received by the public. This might be due to its long-standing nature or to lack of the public's knowledge. Planned IPR is the purposeful augmentation of drinking water supply resources with tertiary or advanced treated wastewater. DPR is the direct reintroduction of the highly treated effluent into the potable water distribution system. IPR can be achieved through augmenting the following three types of drinking water sources with highly treated wastewater: surface waters, reservoirs or groundwaters. Surface water augmentation is the most common form of unplanned IPR while augmenting groundwater is the most common form of planned IPR. Groundwater augmentation for IPR can be achieved in three ways: surface water recharge, vadose zone injection or direct injection (Table 1).

All plants in California, Florida and Arizona were selected for inventorying. Well-known IPR plants in other areas were not inventoried but were reviewed. The inventory was initiated by collecting all available published information on each plant. Next, a visiting plan was developed and contact was made with plant personnel. In most cases, a single interview was made but for some of the more important examples, multiple interviews were conducted. All data that are reported were obtained from plant records. A standard template was used to characterise these facilities by size, technology, type of IPR practised, goals and the outcomes thereof. More specific details such as membrane types, relative costs and specific applicable laws and regulations were also inventoried. Several people were interviewed at each facility and ranged from plant operator to designing engineers. Each facility is summarised in Tables 2–5. More information including a listing of all water quality parameters is presented by Jansen (2005).

Table 1 Characteristics of types of IPR through groundwater recharge

	Surface water recharge	Vadose zone injection	Direct injection
Aquifer type	Unconfined	Unconfined	Unconfined or confined
Pretreatment requirements	Tertiary treatment	Tertiary treatment	Advanced treatment
Capacity (m^3/hectare/day)	100–20,000	1,000–3,000	2,000–6,000
Estimated life cycle (years)	>100	5–20	35–50
Soil aquifer treatment	Vadose and saturated zone	Vadose and saturated zone	Saturated zone

Table 2 IPR projects using injection

Project name and location	IPR Year	Size (m^3/s)	Technology	Notes
1. Water Factory (WF) 21, Fountain Valley, CA.	1976	1.14	Lime clarification, recarbonation, trimedia filtration, GAC + chlorination and pH control + RO	Direct injection, seawater barrier
2. Ground Water Replenishment (GWR) System, Fountain Valley, CA	2003–2020	2.63	Submerged MF, RO, UV/hydrogen peroxide	Direct injection, seawater barrier, NPR
3. West Basin Reclamation Project, El Segundo, CA	1995	0.33	Lime clarification, trimedia filtration, recarbonation + RO and MF + RO + chlorination	Direct injection, seawater barrier, NPR
4. Scottsdale Water Campus, Scottsdale, AZ.	1998	0.44	MF, RO, chlorination	Vadose zone injection, NPR

Table 3 IPR projects using surface water recharge

Project name and location	IPR Year	Size (m^3/s)	Technology	Notes
5. Montebello Forebay, Pomona, CA	1962	1.98	Activated sludge NDN, chlorination, dual media filtration, dechlorination	Surface water recharge 3 plants
6. Chino Valley Basin, Chino Hills CA	1950	0.66	Activated sludge NDN, single media filtration, chlorination–dechlorination (CDC)	Surface water recharge 5 plants, NPR
7. Victor Valley Water Reclamation Authority, Victorville CA	1981	0.50	Activated sludge NDN, trimedia moving bed filters, CDC	Surface water recharge NPR
8. Roger Road Wastewater Plant Tucson, AZ	1983	0.38	Trickling biofilters, chlorination, dual media filters, dechlorination	Surface water recharge NPR
9. Mesa Northwest Water Reclamation Plant, AZ	2003	0.79	Activated sludge NDN, single media filtration, chlorination or UV	Surface water recharge NPR
10. East Central Region WWTP West Palm Beach, FL	2003	0.44	Activated sludge NDN, bridge sand filter, UV	Surface water recharge

Table 4 Failed IPR projects

Project name and location	IPR Year	Size (m^3/s)	Technology	Notes
11. San Diego Water Repurification Project (SDWRP), CA	1985	0.94	Lime clarification, recarbonation, MF, RO, CDC	Reservoir augmentation
12. East Valley Water Recycling Project (EVWRP), Los Angeles, CA	1995	2.0	ASP NDN, rapid sand filtration, CDC	Surface water recharge
13. Tampa Water Recourse Recovery Project, FL	1987	1.5	Lime clarification, recarbonation, filtration, RO or UF or GAC, ozone	Surface water augmentation

Regulatory framework

Federal regulations

Laws amended at a federal level that control water reclamation and IPR are the SDWA and the Federal Water Pollution Control Act often referred to as the Clean Water Act (CWA). The CWA addresses the contamination of the nation's surface waters and regulates discharges therein through permits issued pursuant to NPDES permits, and by limiting the total mass of a specific discharged contaminant through total maximum daily loads (TMDL) limits. The National Primary Drinking Water Regulations (NPDWR) of the SDWA often function as a starting point to define potable water quality objectives, although it was not intended to define these when the source is municipal wastewater. Water quality requirements for IPR usually far exceed NPDWR.

Californian regulations

The California Environmental Protection Agency (Cal/EPA), California Department of Health Services (CDHS) and the California Department of Water Recourses (DWR) are the foremost agencies that regulate water reclamation and IPR. These agencies collectively control water quality, water availability and public health and are responsible for the adoption of regulations involving IPR. The California Regional Water Quality Control Boards (RWQCB), which are subordinate departments of the Cal/EPA, issue requirements for individual projects in conformance with the regulations adopted by DHS. The DWR has an advisory role in this process.

The California State Legislature has declared that the state shall undertake all possible steps to encourage the development of water reclamation facilities so that recycled water may be made available to help meet the state's growing water requirements. California's regulations are the most stringent in the US and are often the precursor of other states'

Table 5 NPR projects

Project name and location	NPR year	Size (m^3/s)	Technology	Notes
14. San Diego North City Water Reclamation Plant, CA	1997	1.3	ASP NDN, dual media filters, chlorination	NPR
15. San Jose Water Pollution Control Plant, San Jose, CA	1979	7.3	ASP NDN, trimedia filters, CDC	NPR
16. Tapia Water Reclamation Facility Malibu, CA	1972	0.42	ASP NDN, dual media filters, CDC	NPR
17. Water Reclamation System St. Petersburg, FL	1977	1.8	ASP NDN, tertiary filters, CDC	NPR, 4 plants
18. Apricot Project, Altamonte Springs, FL	1995	0.44	ASP NDN, trimedia filters, CDC	NPR
19. Orange County Water Reclamation Facilities, Orlando, FL	1986	1.35	ASP NDN, disk filters, CDC	NPR 3 plants

regulation. California state requirements for production, discharge, distribution, and use of recycled water are contained in the following codes:

- California Water Code, Division 7 – Water Quality, Sections 13000–13999.19
- CCR, Title 22 – Social Security, Division 4 – Environmental Health, Chapter 3 – Reclamation Criteria, Sections 60301–60475 (Title 22)
- CCR, Title 17 – Public Health, Division 1 – State Department of Health, Chapter 5 – Sanitation (Environmental), Subchapter 1 – Engineering (sanitary), Group 4 – Drinking Water Supplies, Sections 7583–7630 (Title 17)

There are currently no laws in California that regulate IPR specifically. Title 22 regulations govern the majority of IPR projects and define requirements for sampling and analysis of effluent from wastewater treatment plants, require preparation of an engineering report prior to production or use of recycled water, specify general design criteria for treatment facilities and reliability requirements, and address methods of treatment.

Survey results

Several process configurations were observed among the inventoried facilities. The majority of the facilities consisted of traditional and similar treatment for preliminary, primary and secondary treatment, followed by some type of tertiary or advanced treatment. RO was an essential part of all projects and plans for projects that used groundwater injection or reservoir augmentation methods of IPR. Pretreatment for RO was always practised and took two general forms: older plants used lime clarification, recarbonation and multimedia filtration; newer facilities used MF with facilities under construction or being planned preferring submerged MF. Disinfection was formerly practised using chlorination and dechlorination, but is being displaced by UV light, while hydrogen peroxide is added for advanced oxidation. There was a tendency towards the use of nitrification/denitrification (NDN) in the secondary process to comply with the latest regulations for nitrates.

The following four tables summarise the projects visited in four categories and are arranged per table by location and order of visitation. Table 2 shows the IPR projects practising injection. They all relied on RO to provide a highly treated effluent, free of pathogens, organics and salts, and used source water from activated sludge processes. Table 3 shows surface water recharge IPR projects. RO was not used at any of these plants and influent was domestic wastewater. They all used traditional tertiary treatment which is described in the table because there are slight differences. Table 4 lists the failed IPR projects and Table 5 shows the significant NPR projects.

Discussion

Trends in IPR

Water reclamation in the form of IPR has come a long way since its first attempt back in 1954 in Chanute, Kansas. Health effect studies for the Chino Valley Basin in 1950 and Montebello Forebay in 1962 (Sloss *et al.*, 1996) have showed no adverse health effects of using filtered and disinfected secondary effluent for surface water recharge. Some of the planned versions of IPR in the late 1980s and early 1990s such as the East Valley Water Recycling Project (EVWRP) (1995), the San Diego Water Repurification Project (SDWRP) (1985) and the Tampa Water Recourse Recovery Project in 1987 encountered public resistance which eventually caused the project to fail. In some parts the public resistance was genuine and based upon health fears, and in other parts it appears that political candidates opposed the proposed projects during election campaigns, which elevated public concerns. An incorrect approach to educating the public, such as involvement only after project conception, was partly to blame as well. These projects failed to materialise although they were in most cases identical to existing, successful IPR projects, which demonstrates an inconsistency in decision making.

More recently implemented IPR projects such as the GWR System (2003), West Basin (1995), and the Scottsdale Water Campus (1998) have found the appropriate formula for successful projects. Early and intensive outreach to the general public combined with highly advanced, proven technology ensured the success of the project. These projects also relied upon favourable results from previous pilot projects in other locations, such as Denver (Rogers and Lauer, 1992) and Lake Arrowhead (Madireddi *et al.*, 1997).

Legislative response

The decentralised governing system in the United States has its advantages and disadvantages. Disadvantages have displayed themselves in the early years of this century. Individual water rights and the doctrine of "first in time, first in right", in combination with the limited federal influence have created a climate of complex or uncertain regulations governing new projects. Nearly every newly proposed water project encounters resistance from the public or environmental groups with issues such as dubious ownership of the water rights and environmental impacts. In some cases it is not clear who owns the wastewater and has the right to reuse it. The Colorado River compact is the largest example of ambiguous ownership.

California has predominantly set the standards for the rest of the United States for water reclamation regulations and indirectly for IPR. Many other states practising water reclamation and IPR duplicate regulations set by California. This very aggressive and enterprising approach has made California the front runner (Porter Cologne, Title 22, CASDWA).

Public education has played a key role in the successful IPR projects. The dynamics of a passive and uninformed public and its subsequent overreaction upon becoming aware of the facts have usually halted IPR projects. The Chanute, Kansas project was shut down immediately when the public discovered that their drinking water was recycled. The EVWRP and the SDWRP were IPR projects accepted by the public until political candidates wrongly labelled projects as toilet-to-tap or as social injustice. Such overreactions have strengthened regulations for future projects and in some cases they have become too stringent as revised contaminant action levels (NDMA, 1999) confirm.

Public response

Americans and Californians, in particular, are said to be very accepting of reclaimed water, yet several IPR have failed in the past. The public often understands the logic of using reclaimed water but refrains from using the water themselves. Even though water treatment technology in the US is highly advanced, public acceptance of water reuse has lagged. The influence of conflicting regulations and the limited ability of the governing agencies to cooperatively and successfully implement IPR is a major barrier to its development. In spite of these difficulties, there is an overall growing awareness of the need of reclaimed water.

Studies conducted between 1972 and 1998 (Bruvold, 1988; MacDonald, 1998) show that the public's increasing awareness and knowledge of IPR is improving their ability to make more critical and informed decisions. The opposition to drinking recycled water has increased from 56% to 74% during this period. It must be noted that the respondents from earlier studies were less informed and educated on the subject of water reuse in general and IPR in particular.

The traditional approach of implementing water reclamation projects through the "decide–announce–defend" policy has clearly proven itself to be ineffective. Strategies in which public outreach and education happen after conception are also failing (EVWRP, 1995; SDWRP, 1985) although alternative government systems might succeed (NEWater, Singapore 2003). Newly proposed strategies are to engage stakeholders before project conception and to effectively communicate risks to the stakeholders. This has proven to be the successful approach (GWR System 2003).

The public that perceives a higher social pressure to recycle and has a higher level of awareness for the environment, and subsequently for the conservation of natural resources, is more likely to accept recycled water. Implementation of water reclamation projects encountered more difficulty in societies that do not adopt collective approaches to decision making and problem solving.

Technological response

The technical response to IPR has undergone major developments in recent years. When IPR started in the US in 1954 with the Chanute, Kansas project, only chlorination was used as an additional process and there were no known adverse health effects. IPR facilities performing groundwater recharge through recharge basins in the 1950s later added tertiary filtration with chlorination to their secondary treatment processes. Dechlorination was added in the 1970s when the need to protect aquatic species was realised. Macronutrients (N and P) were next targeted for removal and many facilities converted their aeration tanks to NDN tanks by adding fine air bubble diffusers and anoxic or anaerobic zones (Stenstrom, 1990). More stringent requirements surfaced in the late 1980s when IPR facilities started to directly inject advanced treated wastewater into groundwaters which served as drinking water resources. This caused these facilities to use advanced treatment technologies such as lime clarification, ammonia stripping, activated carbon and granular media filtration. The rapid development in membrane technology has resulted in high rejection RO membranes (Kimura *et al.*, 2004) of which its effluent complied with the stringent regulations for IPR. The success of RO eventually allowed lime clarification, ammonia stripping and carbon adsorption to be phased out. The latest membrane technology is submerged MF. Submerged MF drastically shrinks the footprint of the plant since the MF process is basically integrated with the NDN process. MF processes are now displacing granular media filters.

The most common form of disinfection, chlorination, has virtually disappeared in water reclamation. Problems with chlorination disinfection byproducts have been known for more than 30 years (Richardson, 2003). Chlorine gas is hazardous to handle and agencies responsible for managing hazardous waste are discouraging its transport. UV light is the most popular form of disinfection in today's water reclamation plant. It also avoids production of a popular emerging pollutant, NDMA. UV light has also gained ground because advanced membrane technology provides a better effluent which practically eliminates the shading of potential suspended solids. Ozonation, which was popular for about a decade, is no longer being selected for economic reasons.

Newly emerging pollutants in wastewater are of growing concern. Although not routinely detected for by advanced wastewater treatment facilities, newly emerging pollutants have raised concern for their unknown health effects, fate and transport (Drewes *et al.*, 2002; Kreuzinger *et al.*, 2004). They include heavy metals, endocrine disrupters, pharmaceuticals, hormones, antibiotics, anti-inflammatories and personal care products (Snyder *et al.*, 2003). Advanced oxidation techniques, of which hydrogen peroxide is the most widely encountered form, target these new pollutants. Current detection methods are a limiting factor in identifying these pollutants.

It has been clearly established that IPR through groundwater recharge can be achieved in two different ways. The first and most established form is through recharge basins.

The contemporary form is injection into groundwaters, which requires less land and can be performed in developed areas. Both forms of groundwater recharge have undergone significant changes. Whereas the recharge basins have undergone a slow process of change, direct injection has experienced a rapid development in new techniques. Plants that fall in either category have been reviewed and evaluated on the following parameters, in order of importance, to determine their probability in succeeding:

- Relative cost in relation to location and viable alternatives;
- Involvement of the public (before, during and after conception);
- Outcome of proposed goals;
- Degree of updated technology;
- Degree of establishment (i.e. years in production and recognition for its reliable production);
- Size of IPR component.

Table 6 is an evaluation of the various IPR projects using fuzzy categories for relative successes and failures. Each of the above categories is listed in order of importance and is weighed in conformance with its rank from 6 to 1. Plants score 0 to 5 on these weighted factors for the worst and best representative. These scores are multiplied with the weight and added up to achieve a total score. The total possible score was 105.

Recommendations

In reviewing the various projects, a number of specific items were identified with successful projects. The temptation on the part of proponents of IPR to minimise knowledge in order to avoid opposition usually has just the opposite impact. The following recommendations are made for developing future IPR projects:

- Involving stakeholders before conception;
- Educating the local media;
- Developing basic education and information campaign;
- Using pilot demonstration projects;
- Using credible third-party testimonies;
- Showing successful projects elsewhere;
- Communicating risks to stakeholders;
- Encouraging stakeholders to communicate with each other;
- Increasing public awareness.

Table 6 Evaluation of IPR projects (weight below factors in bold)

Plant	IPR Size	Degree of establishment	Degree of updated technology	Outcome of proposed goals	Public involvement	Relative cost	Total Score
	1	**2**	**3**	**4**	**5**	**6**	
2	5	5	5	5	5	4	**99**
1	3	5	4	5	4	4	**89**
3	1	4	4	5	4	4	**85**
4	1	4	5	5	3	4	**83**
6	3	5	2	3	4	5	**81**
5	4	4	2	3	4	5	**80**
7	3	4	2	4	3	4	**72**
9	3	3	3	3	3	4	**69**
10	3	2	3	3	3	4	**67**
8	3	3	2	3	3	4	**66**
12	4	1	2	1	2	5	**56**
13	4	0	3	1	2	4	**51**
11	3	0	3	1	2	4	**50**

Conclusions

The fight for new water supplies in the United States is over. All water supplies have been allocated. The competition for reclaimed water is next. The technology for water recycle is well developed and this study showed that it was rarely a deciding factor in the success of IPR projects. IPR is becoming an even greater portion of water reclamation and many of the older, failed projects are being revaluated. The most successful projects engaged the general public before conception and maintained communications before, during and after construction. A common occurrence is for agencies to assume that the public is apathetic when they demonstrate little interest. The survey showed that in such cases this leads to project failure because the public soon loses its apathy and opposes the project because they feel uninformed. Continued collection of health risk data associated with IPR is needed.

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