Prospects, problems and pitfalls of urban water reuse: a case study

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Abstract This paper presents a successful water reclamation and reuse project in the San Francisco Bay area. The project, which includes a water reclamation facility and a separate distribution system, is operated by a wastewater utility and reclaims approximately 4% of its dry-weather flow. Project history, its design and implementation are further discussed. Planning, and especially demand analysis, was critical for project development. Earlier attempts of water reuse were not successful because reclaimed water quality did not match the requirements of potential large industrial customers. Current customers are a mix of public, commercial and residential users who apply the reclaimed water solely for landscape irrigation. In addition, a large fraction of the reclaimed water is used internally in the main wastewater treatment plant. Early connection of largest customers, innovative collaboration with a neighboring reclamation project and cooperation of the local water supplier were very important for project success. Distribution of internal process water consumes most energy. The second major energy use is for the treatment of reclaimed water while distribution of reclaimed water to external customers requires least energy.

Keywords Water reclamation and reuse; planning; reclaimed water demand; energy use

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Reclaimed water as a resource

In an urban environment, reclaimed water is typically used for landscape irrigation and impoundments, for fire protection and toilet flushing, and as industrial and commercial process water (Asano and Levine, 1998). The reclaimed water is derived from wastewater after a treatment appropriate for its use. In the U.S., almost all wastewater is treated at least in a secondary (biological) process and disinfected. In California, disinfected secondary effluent can be used for irrigation of urban sites with restricted public access such as golf courses or cemeteries. However, additional filtration preceding disinfection must be applied for unrestricted non-potable urban use. Even when additional treatment (beyond secondary) is not strictly mandated by the law, tertiary filtration is commonly used to increase the flexibility of reclaimed water applications and enhance public perception of water quality. Current regulations impose limits on BOD, pH, turbidity, coliforms and require a minimum chlorine residual in the reclaimed water. Technically, these standards are not difficult to meet and the potential for non-potable water reuse should be substantial. However, many non-technical challenges (regulatory, instititutional, public perception, economic) must be met before a project becomes a reality. This paper discusses some of these challenges and indentifies important solutions based on the experience of a water reclamation and reuse project in the San Francisco Bay area.

Reuse can accommodate water demand during periods of shortage and is often under local control. Thus, the reuse can be viewed as a "resource developed right at the doorstep of the urban environment where water resources are needed the most and priced the highest" (Hermanowicz and Asano, 1998). Despite these advantages and a high potential, water reuse in practice is still quite limited. In 1995, total water reuse in California was $6{\times}10^8$ m^3/yr (485,000 acre-ft) and constituted only 0.6% of total water use (DWR, 1998). Even when measured as a fraction of wastewater discharge, the total water reuse in California can be estimated at approximately 7%. A water reclamation and reuse project requires careful planning (Mills and Asano, 1998) and, even in the best of circumstances, its development and implementation are often fraught with unanticipated problems. This work describes a successful application of water reclamation and reuse in an urban/suburban environment by the Central Contra Costa Sanitary District (CCCSD), a wastewater collection and treatment public utility in the San Francisco Bay area. The district serves an approximate population of 400,000. Wastewater is treated in a full secondary treatment plant with the average dry weather wastewater flow of 1.7×10^5 m^3/d (45 mgd) and the maximum flow during rainy seasons reaching 9.1×10^5 m^3/d (240 mgd). Wastewater passes through pretreatment, primary sedimentation, activated sludge and secondary sedimentation. Secondary effluent is disinfected by UV before the final discharge to the Suisun Bay, the upper part of the San Francisco Bay.

Planning and institutional challenges

The original idea of water reclamation in the CCCSD was conceived in the mid-1970s with the design and construction of a water reclamation facility which included tertiary filtration. The projected ultimate production of reclaimed water was between 1.1×10^5 m^3/d and 1.4×10^5 m^3/d (29 and 36 mgd, respectively) which would make the facility one of the largest in California, even by today's standards. The flow projections were based on an assumption that two major industrial facilities nearby would satisfy part of their demand for process water through reclaimed water. Both facilities required, among others parameters, very low ammonia concentration in the supplied water because of the possibility of brass corrosion. When the reclamation facility was designed, this requirement did not seem too important since nitrification was planned for the total flow of wastewater before the discharge to the receiving water body. However, the regional water authority changed its mind and the nitrification requirement was waived. Thus, no nitrification process was implemented and the requirements of the industrial customers could only be met by a separate nitrification process for reclaimed water only. The construction of a separate nitrification facility was deemed unfeasible at that time and the plans for water reuse did not materialize. The tertiary filtration facility produced a modest volume of water used almost exclusively internally as process water in the main wastewater treatment plant.

After a hiatus lasting until the mid-1990s, the CCCSD began to plan for expansion of water reuse including modernization of the water reclamation facility and substantial extension of the reclaimed water distribution system. During the planning process, the district identified 61 potential customers who expressed an interest in using the reclaimed water for irrigation purposes. Total potential demand projected in the early planning process was 1.4×10^6 m^3/yr (1,100 acre-ft/yr). The district proceeded with the plans, obtained necessary regulatory approvals and rehabilitated the reclamation facility. The new facility, described in more details in the next section, became operational in 1998. Reclaimed water is now distributed to the customers by a new 8 km (5 mi) pipeline with smaller connections which were constructed simultaneously with other parts of the project. As discussed in the next section, demand analysis and early connections of customers were important for project viability.

As another important factor enhancing the chances of success, the CCCSD concluded an agreement to link the district's project with another water reuse project sponsored by the East Bay Municipal Utilities District (EBMUD), a neighboring water and wastewater utility. The CCCSD main pipeline for reclaimed water distribution will be connected to a 29 km (18 mi) pipeline which will serve EBMUD customers. The second pipeline was purchased by the CCCSD from a local refinery after the pipeline's original use, the delivery of jet fuel, was discontinued. Under the agreement between EBMUD and CCCSD, the pipeline will be resold to EBMUD once the connection is completed. The link between the utilities contributed to flexibility of both projects but required very thorough and detailed negotiations and coordination.

Design and operation of water reclamation facility

In the modernized reclamation facility, secondary effluent is drawn through an intake structure from the main plant effluent channel (outfall pipe) and directed to four dual media (anthracite and sand) filters. The design filtration rate was selected at 12.2 m/h (5 gpm/ft^2). Alum and polymer are occasionally applied to improve filtration. After filtration, chlorine is added to the reclaimed water before it flows to a covered clearwell. From the clearwell, the reclaimed water is pumped for distribution in three major directions. Part of the reclaimed water is distributed to the external customers, another part supplies process and landscape water internally in the main wastewater treatment facility, and the remaining part is used for filter backwash. The design flow criteria were determined based on three current and projected water uses: reclaimed water delivered to the external customers, internal plant process water, and filter backwash water. These flow criteria are shown in Table 1. The design value for the average day water demand by the external customers (3.8×10^3 m^3/d or 1 mgd) corresponds to the average reclaimed water demand of 1.4×10^6 m^3/yr (1100 acre-ft/yr) projected during the planning stage. Other flow values were derived from internal plant analysis and historical records.

During its first ten months of operation (May 1998 to February 1999), reclaimed water was delivered to ten external customers out of 61 identified in the process. Figure 1 shows the distribution of projected water demands among all customers identified in the initial plan and the actual demands for the connected customers. The actual demands were annual-

Table 1 Design flow criteria for reclamation facility

	Design flows					
	Average day		Maximum day		Maximum hour	
Water use	10^3 m^3/d	mgd	10^3 m^3/d	mgd	m^3/h	mgd
External customers	3.8	1.0	7.6	2.0	570	3.6
Plant process water	3.4	0.9	5.7	1.5	240	1.5
Filter backwash	0.8	0.2	1.2	0.3	–	–
Total	8.0	2.1	14.5	3.8	810	5.1

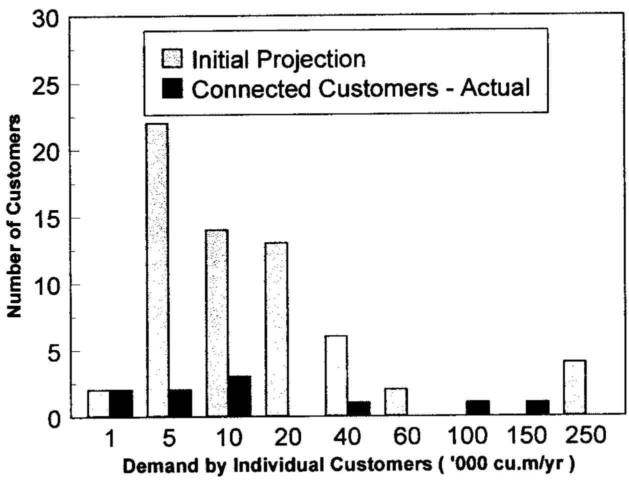

Figure 1 Projected water demand from individual customers

ized by adding the demand from the first two months (March and April) to the end of the ten-month record to make up a full year. This procedure probably underestimated the true future annual demand since the two additional months were the first two months of the operation and water demand tends to increase after the initial start-up.

The initial water demand projections included a large number of smaller customers (between <1,000 and 5,000 m^3/yr, each). Only few of these smaller customers were connected so far. However, the project was able to "capture" the largest customers and connect them early. Although the actual demand from the larger customers was smaller then their projected values, revenues and support received from the large customers was critical for project viability. The actual annual water demand of the ten connected customers was 2.63×10^5 m^3/yr (213 acre-ft/yr) or 19% of the maximum potential for all 61 customers. This ratio, achieved after only ten months of operation, is quite promising but it is obvious that the full demand will be reached only after a longer time. Two additional large customers, which were not initially identified, will be connected by mid-1999.

The reclaimed water customers were classified as public entities (schools, municipal parks, governmental buildings), residential complexes, and commercial enterprises (including hotels, supermarkets, business parks, golf fields, cemeteries). Figure 2 shows that public and commercial entities were dominant, both among all potential customers and those actually connected. No residential customers were yet connected but their projected demand is quite small.

The goal of water reuse is often presented as a replacement of water withdrawn from other sources. In an urban environment, potable water provided by a utility is often the most common such source. In the case of the CCCSD reclaimed water customers, a majority of the potential customers (77% of the projected demand) obtained water from a local water utility which supplied them with two types of water: potable (at approximately \$0.73/m^3 or \$900/acre-ft) and untreated surface water (at half the price). Only 23% of water was supplied from other sources, mostly from individual wells and a small volume from an older reclamation facility (Figure 3). This situation required delicate negotiations between the CCCSD and the local water utility which was faced with a loss of revenue. Currently, among actually connected customers, only a smaller volume of potable (expensive) water has been replaced by the reclaimed water but future expansions will bring this sensitive issue for considerations.

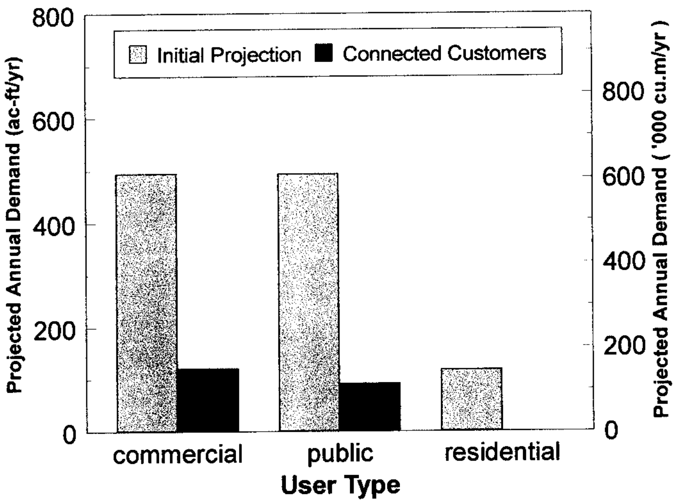

Figure 2 Types of reclaimed water customers

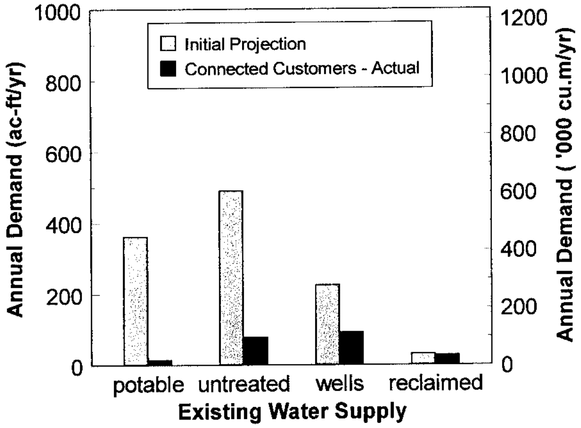

Figure 3 Water supply sources replaced by reclaimed water

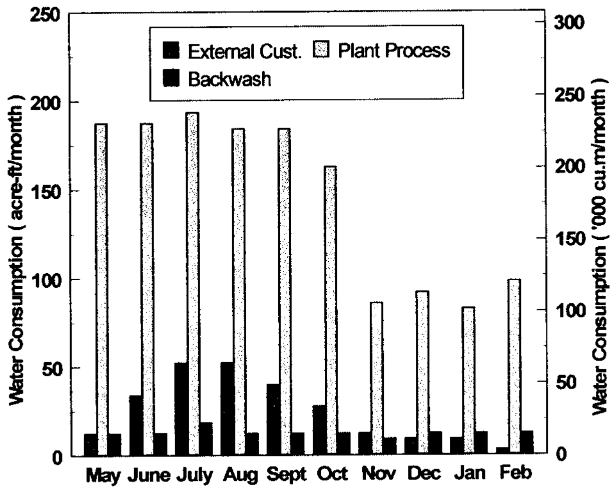

Figure 4 Actual reclaimed water consumption

While initial projections identified annual water demands by potential customers (Figure 1), the actual flows delivered to the connected customers varied during the study period (Figure 4). As the reclaimed water is used by the external customers for landscape irrigation, its demand varied seasonally. Similarly, a portion of the plant process water was also used for landscape irrigation and its use declined in the fall and winter. The backwash water demand varied much less.

As the implementation of this reclamation and reuse project progressed, more information became available about the projected water demand (Figure 5). In the earliest projections, only the demand from 61 potential customers was considered. Although initially only ten customers were connected, the design of the facility was based on the full potential for external demand. In addition, design criteria for process water and backwash were determined. These projected and design values can be compared with the actual annualized water demand based on the first ten months of operation. As seen in Figure 5, the total reclaimed water production was close to the design value. However, water consumption by the external customers was only 19% of the design value indicating a substantial possibility for a further increase. However, the external demand is highly variable. It depends on factors like weather or business climate which are beyond the control of the district.

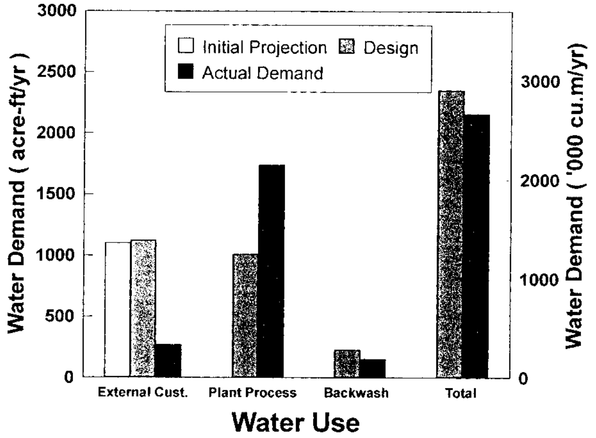

Figure 5 Projected design and actual water flows

One of the objectives of this study was to estimate energy consumption associated with water reuse. A large portion of energy demand comes from the need to pump water between different processes and to supply it to the customers. At the CCCSD water reclamation facility, disinfected secondary effluent is first pumped to the filters from an intake structure on the main plant effluent line. Filtered water then flows by gravity to the clearwell. From the clearwell, reclaimed water is pumped by three sets of pumps into three different distribution systems: for the external customers, for internal process use and for filter backwash. Beside these pumps, there are many much smaller pumps which were ignored in this analysis. Energy requirements for pumping were calculated from recorded pressures and flow rates assuming the overall pump and motor efficiency of 0.6. Independent verification of the energy estimates was not possible because power meters are only available for larger plant systems and not individual pump stations. Figure 6 shows average energy consumption for pumping. The largest portion is for internal process water distribution due to its large flows. To compare energy used for pumping on an equitable base, energy consumption was divided by the total volume pumped and the results are shown in Table 2. The highest energy consumption per unit volume was for water distributed to the external customers, closely followed by plant process water. Although the volume of the intake water is large, its unit energy consumption is the smallest due to the very low pumping head required.

Table 2 shows also unit costs of energy required for pumping. These pumping costs are only a part of the total costs associated with water reclamation. However, it was extremely difficult to apportion exactly other energy uses and other costs because the operation and accounting of the water reclamation facility are integrated with the whole wastewater treatment plant. However, a simple comparison can be made of energy costs for pumping with the revenue obtained from the sale of reclaimed water to the external customers. The rate structure for the reclaimed water contains both a fixed component and a variable component depending on the volume of water consumed. In average, the rate varies from $0.26/m^3 ($325/acre-ft) to $0.47/m^3 ($585/acre-ft). It is interesting to note that the pumping costs alone constitute between 7 and 14% of the water price charged to the customers. Over the ten-month period, the revenue was approximately $114,000 while the energy cost for all major pumping was estimated at $68,000. Thus, it seems that the revenue from the external customer should be sufficient to cover energy costs associated with treatment and distribution of reclaimed water for all purposes.

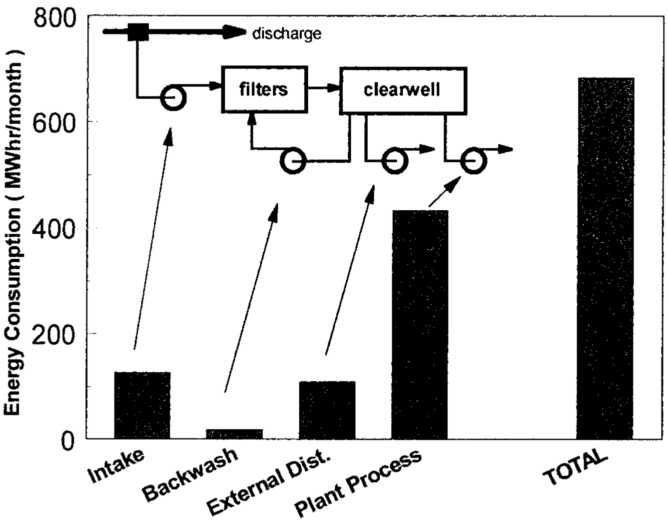

Figure 6 Energy consumption for pumping

Table 2 Energy consumed for pumping

	Pump type				
	Intake	Backwash	External distrib.	Plant process water	Total
Energy/Volume					
kWh/m^3	0.055	0.113	0.346	0.242	0.303
kWh/mgal	210	426	1309	916	1147
kWh/acre-ft	68	139	426	298	374
Energy Cost/Volume (at $0.10 / kWh)					
$/$m^3$	0.0055	0.0113	0.0346	0.0242	0.0303
$/mgal	21	43	131	92	115
$/acre-ft	7	14	43	30	37

Conclusions

Successful development of a water reclamation and reuse project requires careful planning and depends on many factors, not all of which are under the control of project owner or manager. Identification of large customers of reclaimed water and a realistic assessment of their water demand is crucial for project development. Water quality requirements of all customers must be evaluated. If these requirements cannot be met, especially for large potential customers, project feasibility is questionable as shown by the experience of the CCCSD. Large customers should be connected as early as possible to provide both the revenue and the support for project completion. By early connections of the largest customers, the CCCSD achieved a potential for almost 20% of the projected water demand. Both short-term and long-term demand for reclaimed water is highly variable. Project viability may be adversely affected by counting on the project water demand that did not materialize.

Collaboration with other reclamation and reuse projects may be an important factor in achieving a "critical mass" in dealing with stakeholders. Linking the CCCSD project's distribution system to a reuse project of another utility provided a great degree of flexibility and a possibility of additional revenue. In the planning process, existing sources of water supply for the potential customers must be considered. If a substantial consumption of potable water is to be replaced by the reclaimed water, cooperation of water suppliers is needed to mitigate their revenue losses. In the case of the CCCSD project, 44% of reclaimed water demand by connected customers was previously supplied by a local water utility but if all potential customers are eventually connected this value would rise to 77%.

During actual operation, it is difficult to disaggregate both costs and energy consumption but such an effort should be undertaken to provide clear estimates for different parts of the whole project. In this project, the largest fraction of energy was consumed for the distribution of plant process water. Energy consumption for external distribution was relatively small. It seems that the revenue collected from the external customers could cover at least the energy costs of major pumps.

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