REUSE OF WASTEWATER — POSSIBILITIES AND LIMITATIONS
(with an emphasis on potable water reuse)

Hallvard Ødegaard
Projected Water Scarcity in 2025


http://iwmi.org
AN HORRIBLE EXAMPLE - THE ARAL SEA FROM 1976 TO 1997
ERA OF WASTEWATER RECLAMATION, RECYCLING AND REUSE: POST 1960

- California legislation encourages wastewater reclamation, recycling and reuse
- Use of secondary effluent for crop irrigation in Israel
- Research on direct potable reuse in Windhoek, Namibia
- US Clean Water Act to restore and maintain water quality
- Pomona Virus Study; Pomona, CA
- California Wastewater Reclamation Criteria (Title 22)
- Health effects study by LA County Sanitation Districts, CA
- Monterey Wastewater Reclamation Study for Agriculture, CA
- WHO Guidelines for Agricultural and Aquacultural Reuse
- Total Resource Recovery Health Effects Study; City of San Diego, CA
- Potable Water Reuse Demonstration Plant; Denver, CO
  Final Report – plant operation began in 1984

WATER QUALITY DEFINITIONS

- Unpolluted Water
- Water Treatment
- Drinking Water
- Municipal and Industrial Use
- Wastewater Treatment
- Wastewater
- Treated Effluent
- Reclaimed Water
- Repurified Water

Quality of Water vs. Time Sequence (No Scale)
CATEGORIES OF WATER REUSE

1. Agricultural irrigation
2. Landscape irrigation
3. Industrial recycling and reuse
4. Recreational & environmental applications
5. Non-potable urban reuse
6. Groundwater recharge
7. Potable reuse
WASTEWATER REUSE IN CALIFORNIA AND JAPAN

California: 401,910 acre-ft/yr.

Japan: 167,000 acre-ft/yr.

496 x 10^6 m^3 (2000 data)

206 x 10^6 m^3 (1997 data)
WASTEWATER REUSE FOR AGRICULTURAL AND LANDSCAPE IRRIGATION

Most important: The water itself — but also its inherent nutrients

- Irrigation of agricultural land and crops
- Irrigation of sporting grounds (golf courses)
- Irrigation of parks and lawns

The most important challenges:

- Secure hygienic quality
- Prevent soil pollution
- Prevent ground water pollution
CASE: Mexico city

- Hydrological cycle out of balance
- Ground water level sinks 1 m/year
- Ground sinks 10-15 cm/year
- 45 m³/sec wastewater
- Only 29 m³/sec stays within area
RAW WASTEWATER IRRIGATION IN MEXTAL VALLEY WHERE VEGETABLES ARE GROWN

Ascaris frequent among population

After irrigation

Before irrigation
REUSE OF WASTEWATER FOR URBAN LANDSCAPING

Treated wastewater for landscaping (ponds, creeks, wetlands etc.)

Wetland

Creek from wastewater
CALIFORNIANS ARE BATHING IN THE WWTP OUTLET
REUSE OF WASTEWATER FOR URBAN USE

Treatment of grey-water to be used for toilet flushing

Two principal systems:
• one for the whole town
• local, small-scale systems
REUSE OF WASTEWATER IN MEGACITIES (Example Tokyo)
**RECLAIMED WASTEWATER FOR INDUSTRIAL REUSE**

**Reuse within the industry**

- Reuse of reclaimed municipal wastewater
  - cooling-system make-up water
  - boiler feed water
  - process water for production
    - manufacturing
    - iron and steel
    - textile
  - wash-down water (car wash)
RECLAIMED WASTEWATER FOR POTABLE WATER SUPPLY

Direct potable reuse:

- Very seldom - Not because of inability to treat sufficiently, but because of the public’s objection to drink former sewage
- Example: Windhoek, Namibia

Groundwater recharge

- Quite common -
  - Arresting the decline of water level
  - Storage of surface water
  - Self purification in soil
- Example: West Basin, California
WHY POTABLE WATER REUSE?

- Introduced due to water shortage
- Made possible because of advanced treatment technologies
- Health and safety aspects have resulted in a cautious attitude
- Implemented in communities with no other freshwater supply options
- Small volumes, but great interest from a technological and public health point of view
Case: Windhoek, Namibia

- Population of about 250,000
- Severe water shortage in the late sixties
  - Reclamation of municipal wastewater for potable reuse was the only short-term solution
- Following pilot-scale testing, a potable reclamation plant was opened in 1971
- Capacity: 4,800 m³/d
- Several upgrades, and the capacity is now being expanded to 21,000 m³/d
1971 Flotation, filtration, carbon filtration and chlorine disinfection

1977 Lime enhanced settling. Ammonia stripping

1980 Alum and lime addition before settling

1986 Alum addition and dissolved air flotation
BLENDING OF RECLAIMED WATER

- Blended with conventionally treated water in two steps
  - Blending with treated surface water at the treatment plant
    - Minimum of 1:1 dilution, average 1:3.5
  - In the bulk water system of Windhoek
    - Distribution only to a limited number of supply zones

- In the future, the surface water supply will have almost no benefit compared to the reclaimed water due to deterioration of the surface water
- Increased use of reclaimed water
CONTRIBUTION FROM RECLAIMED WATER

The graph illustrates the contribution from reclaimed water over the years 1970 to 1994. The x-axis represents the years, while the y-axis shows the reclaimed water demand. The graph compares the reclaimed water to the total demand, with bars indicating the reclaimed water demand and hatched bars showing the total demand. The data highlights the increasing trend of reclaimed water demand over the years.
### MONITORING OF THE WATER QUALITY

- **Chemical**: Main chemical constituents
- **Toxicity**: Water flea lethality, urease enzyme activity, bacterial growth inhibition
- **Virological**: Somatic coliphages is used as an indicator for the presence of viruses, 100% negative
- **Bacteriological**: 86% < 100 CFU/ml, 3 + on coliform
- **Algal**: Chlorophyll levels
- **Mutagenicity**: Ames salmonella mutagenicity
- **Mortality pattern**: Patterns of mortality and cancer were not affected by reclamation
- **Monitoring represents**: 20% of the total production cost
SUCCESS FACTORS FOR THE WINDHOEK-PROJECT

- The public was kept fully informed at all stages
- Separation of industrial and potentially toxic wastewater
- Adequate and consistent effluent quality produced by the secondary wastewater treatment
- Advanced treatment producing acceptable potable water
- Multi-barrier treatment sequence as a safeguard against pathogens
The Windhoek experience with wastewater reclamation to potable drinking water standards was an unqualified success during its first 25 years.

If properly informed, consumers will fully accept this perhaps controversial option.

The cost of reclamation was less than the cost of diverting water over long distances from other sources.

Reclamation and reuse is a practical option, not only for technologically advanced countries.

Dr. Lucas van Vuuren:
"Water should not be judged by its history, but by its quality"
From the 1950’s imported water have been injected into the ground to protect the aquifers against sea water intrusion.

Groundwater accounts for more than 20 % of the water consumption.

From June 1995, 19 000 m$^3$/d of highly treated reclaimed water was mixed with imported surface water and injected into the West Coast Basin Barrier.

A baseline groundwater monitoring program was initiated in 1991 for comparison purposes.

Case: West Basin, California
Comparison of Water Withdrawals, By States, in 1980.

The Californians use a lot of water.

The total national rate of withdrawal of ground and surface water was 450 billion gallons per day.
WEST BASIN WATER RECLAMATION PLANT

Secondary effluent → Aeration → Lime clarification → Recarbonation → Filtration → Reverse osmosis → Chlorine disinfection → Deep well injection

Aquifer recharge
WATER QUALITY REGULATIONS

Reclaimed water (to meet drinking water standard)

- BOD$_5$ < 1 mg/l
- SS < 1 mg/l
- Turbidity < 2 NTU
- TOC < 2 mg/l
- Total coliform < 2.2 per 100 ml
- pH 6.5-8.5
- Oil and grease < 1 mg/l

Groundwater recharge proposed regulations

- Retained in aquifer for 12 months prior to extraction
- Maximum 50% reclaimed water within 700 m from extraction well
- Injected water should travel at least 700 m prior to extraction
TRACE ORGANIC COMPOUNDS

- Traditionally organic micropollutants have been monitored according to drinking water standards by following some target compounds.

- Several investigations have shown that many other “non-target” compounds are present.

- Levine et al. (2001):
  - Trace organic compounds found were primarily disinfection byproducts as chloroform and bromoform.
  - A possible release of base neutral compounds after lime clarification due to the high pH.
  - RO is an effective remover of organic micropollutants.
Use of 50% reclaimed water for injection is anticipated to improve groundwater quality.

Cost of the 19,000 m³/d reclamation plant was about $22 million.

Will be built out in 19,000 m³/d increments to 76,000 m³/d (extra $40 million).

The goal is to substitute all the treated, imported surface water currently used for the West Coast Basin Barrier by reclaimed water.
THE POTENTIAL FOR POTABLE WATER REUSE

- Treatment technology exist and is continuously improved.
- Pioneer projects have showed that it is possible, and this might help public acceptance.
- Possibilities for multi-quality recycled water production.
- Diversion of industrial and potential toxic wastewater from the main wastewater stream.
LIMITATIONS IN POTABLE REUSE

- Public acceptance
- Pathogen transmission control
- Cost competitive compared to other possibilities (desalination, water import)
- Organic chemicals from reclaimed wastewater and their toxicological effect
- Demands highly advanced analysis technology
Drinking water standards are normally based on the assumption that high quality water sources are used.

- The concept of multiple barriers was introduced primarily for increased safety against pathogenic organisms.

Goal: indirect potable reuse should provide a degree of safety at least equal to that of a community's current water supply.

Health effect testing based on the effects of indirect potable reused water as compared to conventional water supplies.

Additional safeguards:

- Blending and dilution with conventional raw water
- Retention time
- Natural treatment
HOW SAFE IS WATER REUSE?

- Acceptable health risks debate
  - Absolute risk vs. relative risk
- Microbiological risk assessment
  - Enteric virus control by treatment technologies
  - Regulatory oversight
- Chemical exposure risk assessment

Exposure Assessment

<table>
<thead>
<tr>
<th>ppt</th>
<th>ppb</th>
<th>ppm</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excess Risk</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 in 100,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 in 10,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 in 1,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 in 100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 in 10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Extrapolation from animal studies

Clinical observation

Largest epidemiological studies

Most epidemiological studies
RISK ASSESSMENT

- Treatment plant
  - Pathogens and source
  - Reclaimed water transport
- Environment
  - Route of exposure
- People
  - Infection, illness
  - Target organ
  - Recovery
  - Death

Hazard identification

Exposure Assessment

Risk characterisation

Dose-response relationship
POTABLE REUSE REGULATIONS

- International level
  - No regulations for potable reuse

- U.S
  - No federal regulations - state level
  - California, Proposed regulations for potable recharge
    - The groundwater supply should meet all drinking water standards and require no treatment prior to distribution

- In general:
  Reclaimed water for potable reuse must meet drinking water standards
SOME QUESTIONS THAT NEED TO BE ANSWERED

1

• What is the likelihood that hazardous substances will be present in the reclaimed water at harmful levels?

• What is the known chemistry and toxicology of the reclaimed water or groundwater and how much of the organic material present is uncharacterized?
SOME QUESTIONS THAT NEED TO BE ANSWERED

• What is the best disinfectant or disinfection process for groundwater recharge?

• What are the upper bound, lower bound and most probable risks that could be attributed to lifetime consumption of the reclaimed water, as well as other sources of drinking water?
SOME QUESTIONS THAT NEED TO BE ANSWERED

- To what degree do costs influence the treatment alternatives, at the margin, relative to upper bound and most probable risks?

- Which portion of the TOC and the total halogenated organics should be removed by treatment barriers?
SOME QUESTIONS THAT NEED TO BE ANSWERED

4

• What additional costs would be incurred if groundwater quality changes resulting from recharge necessitated the future the centralized treatment and distribution of extracted groundwater?

• Is the indirect potable reuse the last resort?
TREATMENT TECHNOLOGIES THAT PROBABLY WILL HAVE TO BE INCLUDED

Oxidation/disinfection technologies
Ozonation/UV, H₂O₂ etc

Advanced separation technologies
Membrane separation