GW·MATE

THE WORLD BANK
global water partnership associate program

Sustainable Groundwater Management
Concepts & Tools

Briefing Note Series Note 12

30104 rev

Urban Wastewater as Groundwater Recharge

evaluating and managing the risks and benefits

2005

Authors (GW•MATE Core Group)

Stephen Foster[1] Héctor Garduño[1] Albert Tuinhof[2] Karin Kemper Marcella Nanni

([1]lead author [2]main supporting author)

How does urban wastewater relate to groundwater?

- The expansion of waterborne sewerage in developing cities has gone on intermittently over many decades, with the earliest small systems having been introduced during the first half of the 20th century. Although sewerage provision lags behind water supply, rapid growth in urban water demand is resulting in steadily-increasing wastewater generation by most developing cites, and this will be further stimulated by the UN Millennium Goals for sanitation. Many sewerage systems discharge directly to surface watercourses with minimal treatment and little dilution in the dry season, and thus the 'wastewater' available for irrigation reuse can often be (in effect) largely sewage effluent.

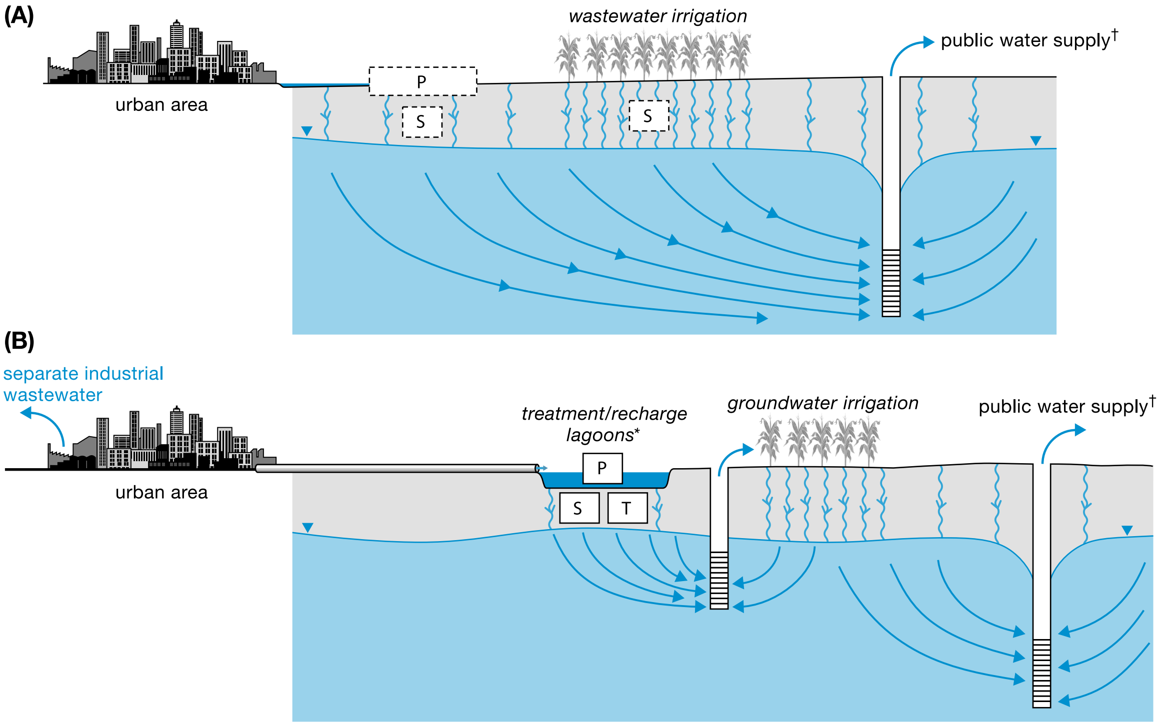
- It has also become apparent that common wastewater handling and reuse practices in developing nations (which are frequently unplanned and uncontrolled) generate high rates of infiltration to underlying aquifers in the more arid climates. This incidental infiltration is often volumetrically the most significant local 'reuse' of urban wastewater, but one which is rarely planned and may not even be recognized. It both improves wastewater quality and stores it for future use, but can also pollute aquifers used for potable water supply. The topic has major implications in terms of future approaches to groundwater and wastewater management in many rapidly-developing urban centers.

- The wastewater recharge occurs regardless of whether the urban area is served primarily by:
  - on-site sanitation facilities, with direct soil discharge on a diffuse basis via septic tanks and latrines
  - sewerage systems, with effluent discharge downstream of the urban center and reuse for irrigation.

  This note deals only with the latter situation. Acknowledging the potential benefits of wastewater reuse for agricultural irrigation and aquifer recharge, the focus is on evaluating the consequences of common practices of sewage handling and reuse in developing cities (Figure 1A) and on cost-effective incremental approaches to reducing the groundwater pollution risk (Figure 1B).

- Wastewater infiltration to groundwater occurs directly from effluent handling facilities and indirectly from excess agricultural irrigation in downstream riparian areas. Research under these conditions has been carried out in a number of areas (Table 1), and there is clear evidence of groundwater recharge at unit rates of more than 1000-mm/a. It can thus be argued that major incidental aquifer recharge is ubiquitous and should always be anticipated as an integral part of wastewater reuse processes.

Figure 1: General schemes of wastewater generation, treatment, reuse and infiltration to aquifers
(A) commonly-occurring unplanned and uncontrolled situation
(B) economical interventions aimed at reducing groundwater source pollution risk



P/S/T | P/S/T — effective level of wastewater treatment (P= primary; S = secondary; T = tertiary); dotted box indicates incidental (unplanned) process

* treatment plant can subsitute for lagoons (especially where land is at a premium) providing that higher capital and running costs are acceptable
† should have appropriate surveillance and treatment

- Wastewater is very popular with poorer farmers, because of its continuous availability, large organic load and high plant nutrient content. But there are instances of indiscriminate practices of very high public health risk, such as irrigation with raw sewage and cultivation of crops eaten uncooked. There may also be longer-term hazards if industrial effluent is present, such as build-up of toxic elements (notably lead, chromium, boron, etc.) in soils, reduction of soil fertility and possible uptake into the food chain, but these important inter-related topics are outside the current scope.

To what extent is wastewater a groundwater pollution hazard?

- The range of potential groundwater pollutants in wastewater includes pathogenic microorganisms, excess nutrients and dissolved organic carbon, and where significant industrial effluent is present, toxic heavy metals and organic compounds. However, the actual effect on groundwater quality will vary widely with:
  - the pollution vulnerability of the aquifer (**Briefing Note 8**)
  - the quality of natural groundwater and thus its potential use
  - the origin of sewage effluent and thus likelihood of persistent contaminants
  - the quality of wastewater, and its level of treatment and dilution
  - the scale of wastewater infiltration compared to that of aquifer throughflow
  - the mode of wastewater handling and land application.

- For common wastewater reuse practices employing unlined distribution reservoirs and with flood irrigation at field level, there is likely to be significant penetration of pathogenic bacteria and viruses to aquifers in conditions of shallow water table or near-surface fractured aquifers. But in most other conditions vadose zone attenuation will be effective in eliminating most pathogens (Figure 2) before they reach the water table and (in this sense) in achieving tertiary-level wastewater treatment.

- However, even under favorable conditions in terms of aquifer vulnerability and wastewater quality, the wastewater infiltration process alone cannot achieve strict potable water-quality standards in phreatic aquifers. This is mainly a consequence of the following:
  - wastewater nitrogen content considerably exceeds plant requirements with leaching from irrigated soils and resultant nitrate (NO_3) concentrations of over 45 mg/l in groundwater recharge (Table 1)
  - where wastewater infiltrates directly ammonical-nitrogen (NH_4) is generally the stable nitrogen species and likely to reach troublesome levels (Table 1)
  - elevated dissolved organic carbon (DOC) concentrations, typically 3–5 mg/l and peaking at 6–9-mg/l (Figure 3), compared to normal background levels of less than 1–2 mg/l.

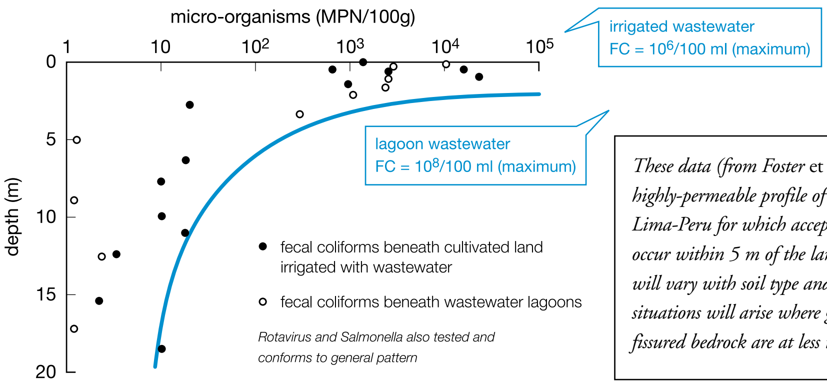
- These elevated DOC concentrations give rise to two associated concerns:
  - potential for the formation of harmful trihalomethanes (THMs) if the groundwater is disinfected for potable supply—'affected groundwaters' from the research areas had a 'DOC reactivity' of 20–45-µg/mg and some samples recorded relatively high THM formation potential values of over 100 µg/l
  - possibility that the DOC (mainly humic-like acids and some sterols, phthalates, phenols, detergents and a variety of 'not positively identified compounds') could also include trace levels of man-made organic chemicals potentially harmful to human health—although carcinogenic compounds, endocrine disrupters or other hazardous chemicals have rarely been confirmed in groundwater.

Table 1: Typical composition† of shallowest groundwater affected by wastewater infiltration in research areas at time of study

LOCATION	TREATMENT LEVEL	AQUIFER VULNERABILITY	SELECTED DISSOLVED CONSTITUENTS (mg/l) Na	Cl	NO_3	NH_4	B	DO_2	DOC	TRACE ELEMENTS^
Lima Suburb–Peru^^	primary or secondary	moderate	90/85	182/168	40/85	3.2/0.8	n/a	n/a	5/4	n/a
Wadi Dhuleil–Jordan*		high	570*	1190*	130	1.3	1.2	2	3	Mn, Zn
Mezquital Valley-Mexico	none, but equivalent primary within distribution system	variable; generally moderate but locally high	240	220	60	< 0.1	0.8	3	4	As
Leon (Gto)–Mexico**			210	340	40	< 0.1	0.3	2	4	Mn, Ni, Cr, Zn
Hat Yai-Thailand		low	40	50	< 1	6.2	<0.1	0	3	Mn, Fe, As

† data from BGS *et al.*, 1998 ^ indicates those detected in low concentrations ^^ separate values given for aquifer beneath treatment lagoons/irrigated fields
* aquifer also subject to some saline intrusion ** wastewater has major industrial component na not analyzed

Figure 2: Vadose zone attenuation of fecal pathogens from wastewater infiltration



These data (from Foster et al.*, 1994) are for a deep highly-permeable profile of aeolian sand at a site in Lima-Peru for which acceptable levels of attenuation occur within 5 m of the land surface; this depth will vary with soil type and the most vulnerable situations will arise where groundwater table and/or fissured bedrock are at less than 3 m depth.*

What types of measures are available for reducing risks and increasing benefits?

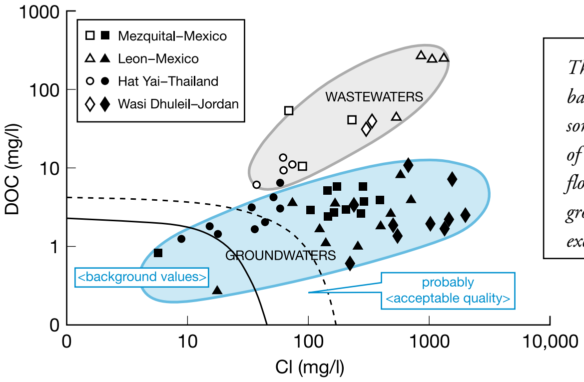
- Because groundwater is often the preferred source of public water supply, and is also widely exploited for private domestic and sensitive industrial use, aquifer pollution hazard is a serious consideration. However, little progress in reducing this hazard is likely to be made in the developing world by simply advocating rigorous quality standards. Indeed the existence of such standards can be counterproductive, often leading environmental health agencies to 'turn a blind eye' to the situation because they do not have the personnel capacity and financial resources to respond.

- There is a pressing need to confront the reality of current practices pragmatically, by identifying where cost-effective interventions and incremental investments can best be made to reduce the risks to groundwater users (Figure 1B), rather than blindly constructing conventional sewage treatment works of questionable operational sustainability. These priority actions then need to be pursued consistently (as part of a package which includes actions directed at other critical issues such as cropping controls, farm-worker health and soil fertility), with participation of the representatives of all the rural and urban stakeholders involved.

- A high priority will always be to improve wastewater characterization as an aid to the assessment of groundwater pollution hazard. Where potential problems associated with persistent contaminants that pose a threat to groundwater quality become apparent (such as high salinity or certain toxic industrial organic and inorganic chemicals), the best approach will be to evaluate their origin within the overall sewerage system and establish the feasibility of control at source or separate collection and disposal.

- The impact of wastewater infiltration on specific groundwater supply sources will depend not only on its impact on the shallow aquifer system, but also on their siting relative to wastewater infiltration area, their depth of water intake and the integrity of well construction. With careful control of such factors (and under favorable circumstances in terms of aquifer vulnerability and wastewater quality), compatibility between wastewater reuse and groundwater supply interests can be achieved through:
  - increasing the depth and improving the sanitary sealing of potable waterwells
  - establishing appropriate source protection areas for such waterwells
  - increasing groundwater monitoring for the indicators discussed above
  - using irrigation wells to recover most of the wastewater infiltration and provide a 'hydraulic barrier' for the protection of potable water supplies

Figure 3: Cl and DOC concentrations in groundwater from wastewater infiltration research areas



The range of increases in shallow groundwaters above normal background values is illustrated here (data from BGS et al.*, 1998); some sewage effluent has elevated salinity levels as a consequence of exfiltration to sewers of brackish soil water and/or substantial flow contributions from saline industrial discharge, and can lead to groundwater recharge from wastewater infiltration containing in excess of 250 mg Cl/l.*

- improving irrigation water-use efficiency and thus wastewater recharge to underlying aquifers
- urging constraints on the use of shallow private domestic wells.

How can wastewater and groundwater use be integrated into urban planning?

- A related question is how can future urban wastewater engineering take adequate account of groundwater resource interests. Current decisions to extend mains sewerage coverage are normally taken in relation to the following technical and social factors:
  - inadequate subsoil capacity to dispose of liquid effluent due to the presence of low-permeability surface strata and/or high water table, causing malfunction and overflow of *in situ* sanitation units
  - high-density residential development with inadequate access and/or space for removal of solid residues from *in situ* sanitation units.

- Sufficient consideration is not given to the new environmental problems that will be created by generation of sewage effluent, compared to those of existing *in situ* sanitation and its potential upgrade to higher ecological standard. Nor is adequate emphasis placed on water resource issues such as:
  - providing additional water supply for amenity or agricultural irrigation through wastewater reuse in areas of low aquifer pollution vulnerability, as a means of conserving potable-quality groundwater
  - reduction of the ingress of saline groundwater into sewers in arid areas
  - reducing the pollution hazard to municipal and private wells situated within the urban area
  - increasing water-supply needs for waterborne sewerage, likely to be met in part from groundwater
  - recognizing that aquifer storage of reclaimed wastewater will often be the best overall option where demand for irrigation water exhibits large seasonal variation, and using infiltration through the vadose zone of aquifers for tertiary treatment of wastewater.

- To achieve a more integrated approach significant institutional questions must be addressed:
  - which agency should have final responsibility for wastewater management?
  - what should be the respective legal obligations of wastewater generators and users?
  - how best can a broader base of stakeholder consultation be introduced?
  - how should wastewater discharge permits consider reuse factors?
  - how can training on wasterwater-groundwater relations best be implemented?

- The groundwater dimension is thus still often one of the 'missing links'. Major incidental recharge of aquifers through wastewater handling and reuse is so widespread that it should always be contemplated as an integral part of wastewater management, and thus planned for accordingly. Those responsible for wastewater need to be made aware of the benefits and hazards of wastewater recharge to aquifers, and how hydrogeological environments vary with regard to pollution vulnerability, and thus to wastewater safe loading rates and patterns. A stronger element of municipal planning will be needed for the worst (and least sustainable) of past practices to be avoided in future.

Further Reading

- BGS, CNA, SAPAL, WAJ, DMR and PSU. 1998. Protecting groundwater beneath wastewater recharge sites. *BGS Technical Report WC/98/39.*
- Bouwer, H. 1991. Groundwater recharge with sewage effluent. *Water Science & Technology 23: 2099–2108.*
- Dillon, P. J. 2002. Management of aquifer recharge for sustainability. *Proc. 4th International Symposium on Artificial Recharge of Groundwater* (Adelaide, September 2002). Balkema Publishers. Rotterdam, Netherlands
- Foster, S. S. D., Gale, I. N. and Hespanhol, I. 1994. Impacts of wastewater reuse and disposal on groundwater. *BGS Technical Report WD/94/55.*
- Foster, S. S. D., Lawrence, A. R. and Morris, B. L. 1997. Groundwater in urban development: assessing management needs and formulating policy strategies. *World Bank Technical Paper 390.* Washington, D.C., USA.
- George, D. B., Leftwhich, D. B., Klein, N. A. and Claborn, B. J. 1987. Redesign of a land treatment system to protect groundwater. *Journal of Water Pollution Control Federation* 59: 813–820.
- Idelovitch, E. and Michail, M. 1984. Soil-Aquifer Treatment—a new approach to an old method of wastewater reuse. *Journal of Water Pollution Control Federation* 56: 936–943.
- Jimenez, B. and Garduno, H. 2002. Social, political and scientific dilemmas for massive wastewater reuse in the world. In AWWA Publication *Navigating Rough Waters—Ethical Issues in the Water Industry*.

Publication Arrangements

The GW•MATE Briefing Notes Series is published by the World Bank, Washington D.C., USA. It is also available in electronic form on the World Bank water resources website (www.worldbank.org/gwmate) and the Global Water Partnership website (www.gwpforum.org).

Funding Support

bnwpp

GW•MATE (Groundwater Management Advisory Team) is a component of the Bank-Netherlands Water Partnership Program (BNWPP) using trust funds from the Dutch and British governments.

DFID Department for International Development