
# The EU funded SWIM-SM: developing capacity for Sustainable and Integrated Wastewater Treatment and Reuse

*Online Course on Natural Treatment Systems: Soil Aquifer Treatment*

Dr. Martin Mulenga – UNESCO-IHE

# Soil Aquifer Treatment

# Objectives and Learning Outcomes of the course

**Objective:**

- To provide a basic description and understanding of the processes used in the treatment of wastewater by the Soil Aquifer Treatment System

**Intended Learning Outcomes:**

On successfully completing the module, the participants should be able to -

- Understand the fundamental, scientific basis governing the design and performance and operation and maintenance of the Soil Aquifer Treatment systems
- Apply their knowledge of the Soil Aquifer Treatment systems in their work
- Be familiar with the terminology applied to Soil Aquifer Treatment systems and the design parameters

# Topics

1. Introduction
2. Types of MAR Systems
3. What is SAT?
4. Soil Aquifer Treatment Process
5. Types of SAT
6. Infiltration Rates in SAT
7. Advantages and Limitations
8. Factors affecting performance of SAT systems
9. Site Selection
10. Planning and Design
11. Operation and Maintenance
12. Case Studies
13. Conclusions
14. Further Reading

# INTRODUCTION

- Increasing population growth, industrialisation and climate change are contributing to water stress & deterioration of fresh water sources
- To counter that – effective water resources management methods are required
- Example – Managed Aquifer Recharge (MAR) which comprises a wide variety of systems in which water is deliberately introduced into an aquifer with the objectives to:
  a. Introduce an additional barrier for treatment of water for a specific use (main focus of lecture)
  b. Store excess water during the rainy season to be used in dry periods (mainly used in arid and semi-arid regions)
  c. Reduce the risk of intrusion of impaired water (e.g. in coastal aquifers)

# Types of MAR Systems for Groundwater Recharge

1. Dune filtration
2. Infiltration ponds
3. Bank filtration
4. Percolation tank
5. Soil Aquifer Treatment (SAT)
6. Underground Dam
7. Sand Dam
8. Recharge Release

Two Types of Groundwater Recharge –

- Through soil and subsoil passage
- Direct entrance (injection) into aquifer

# What is Soil Aquifer Treatment (SAT)?

- SAT is a geo-purification system which utilises physical, chemical & biological processes during infiltration of wastewater effluent through soil strata to improve water quality
- SAT is  a form of managed aquifer recharge (MAR) technology, which alone or in combination with other wastewater treatment technologies can produce effluent suitable for indirect potable reuse.
- Relatively low cost and can be an alternative to fresh water sources for:
  - ➢ Agricultural and park irrigation
  - ➢ Sea water intrusion
  - ➢ Municipal uses
- SAT employing primary effluent is an attractive option for low-income countries as this does not require considerable wastewater treatment plant operator expertise

# The Soil Aquifer Treatment Process

- Soil aquifer treatment provides wastewater treatment during the vertical infiltration of wastewater effluent through the unsaturated zone (vadose) and eventually during its horizontal movement in the saturated zone before it s abstracted again from a recovery well.

- Treatment is done in 3 steps:

    - Surface infiltration
    - Percolation through the unsaturated zone (vadose zone)
    - Slow transport through the aquifer

(See Figure 1 below)

# Schematic layout of Soil Aquifer Treatment

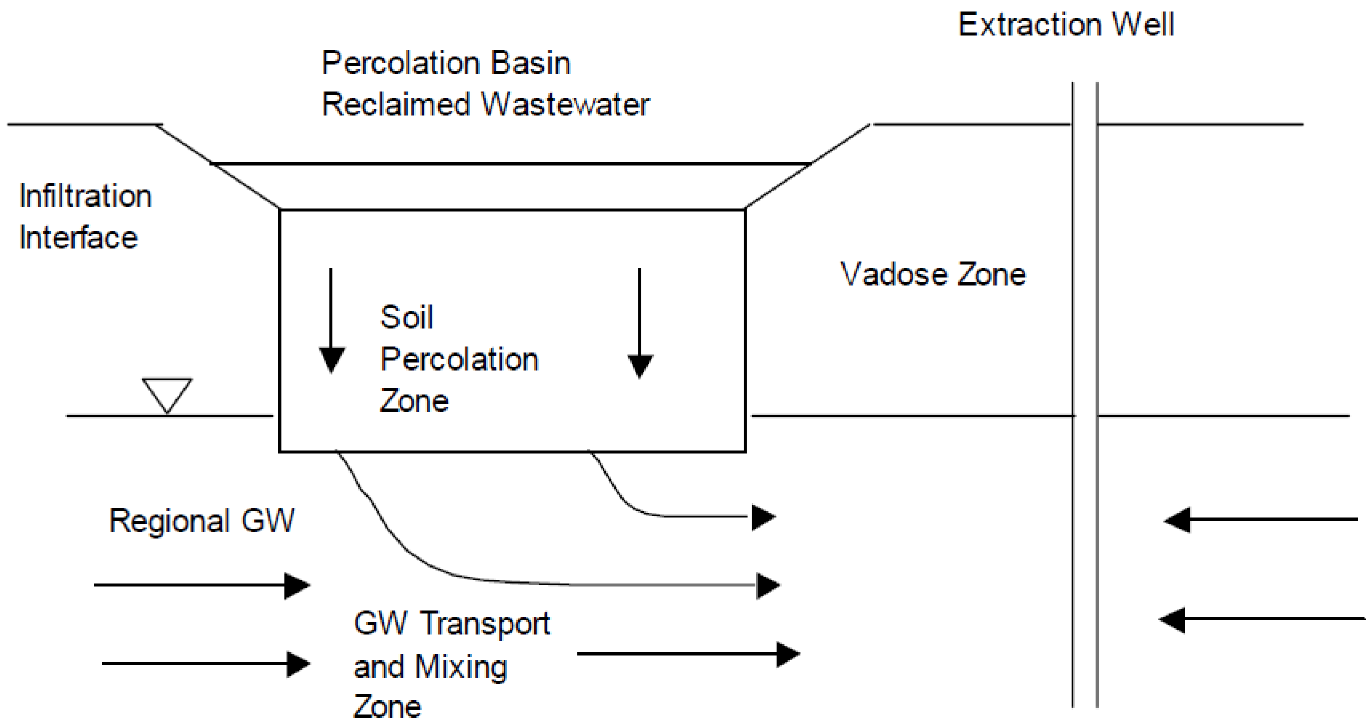
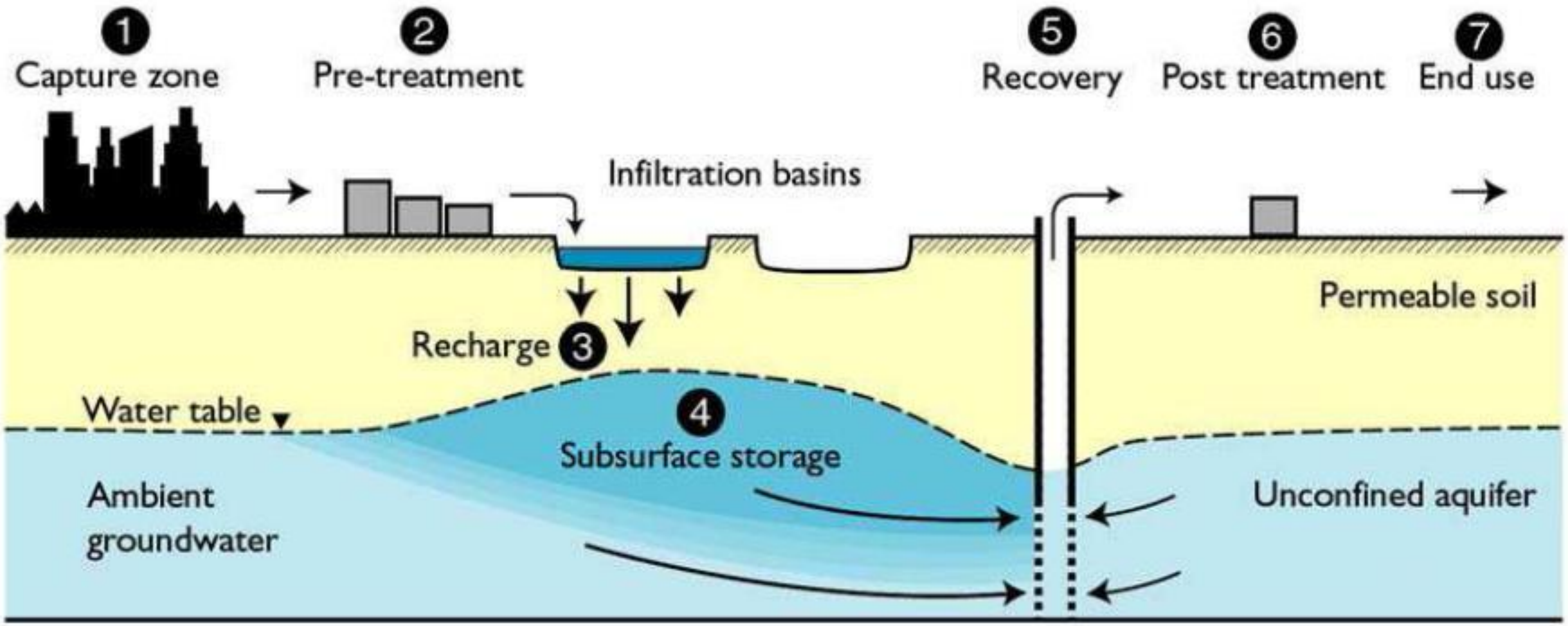



Figure 1 - Source: Fox et al. 2001

# SAT for pre-treated wastewater




SAT system for pre-treated wastewater, infiltrating through recharge basins into permeable soil (unsaturated zone) and recharging the groundwater aquifer. Source: MIOTLINSKI et al. (2010)

- Dissolved organic matter is removed by combined biological, chemical, & physical processes mostly in the vadose zone (the unsaturated zone).

- The vadose zone & aquifer act as natural, slow filters that effectively reduce the concentration of various pollutants due to physical, chemical, and microbiological processes.

- Suspended solids are filtered; biodegradable organic compounds are decomposed; microorganisms are adsorbed out or die due to competition with other soil microorganisms; nitrogen concentrations are reduced by denitrification; synthetic organic compounds are adsorbed and/or biodegraded; & phosphate, fluoride, & heavy metals are adsorbed, precipitated, or otherwise immobilised.

# Types of Soil Aquifer Treatment

There are 3 types of SAT systems:

i. Infiltration basins
ii. Vadose zone wells
iii. Direct injection well

See Figure 2

# SAT Types

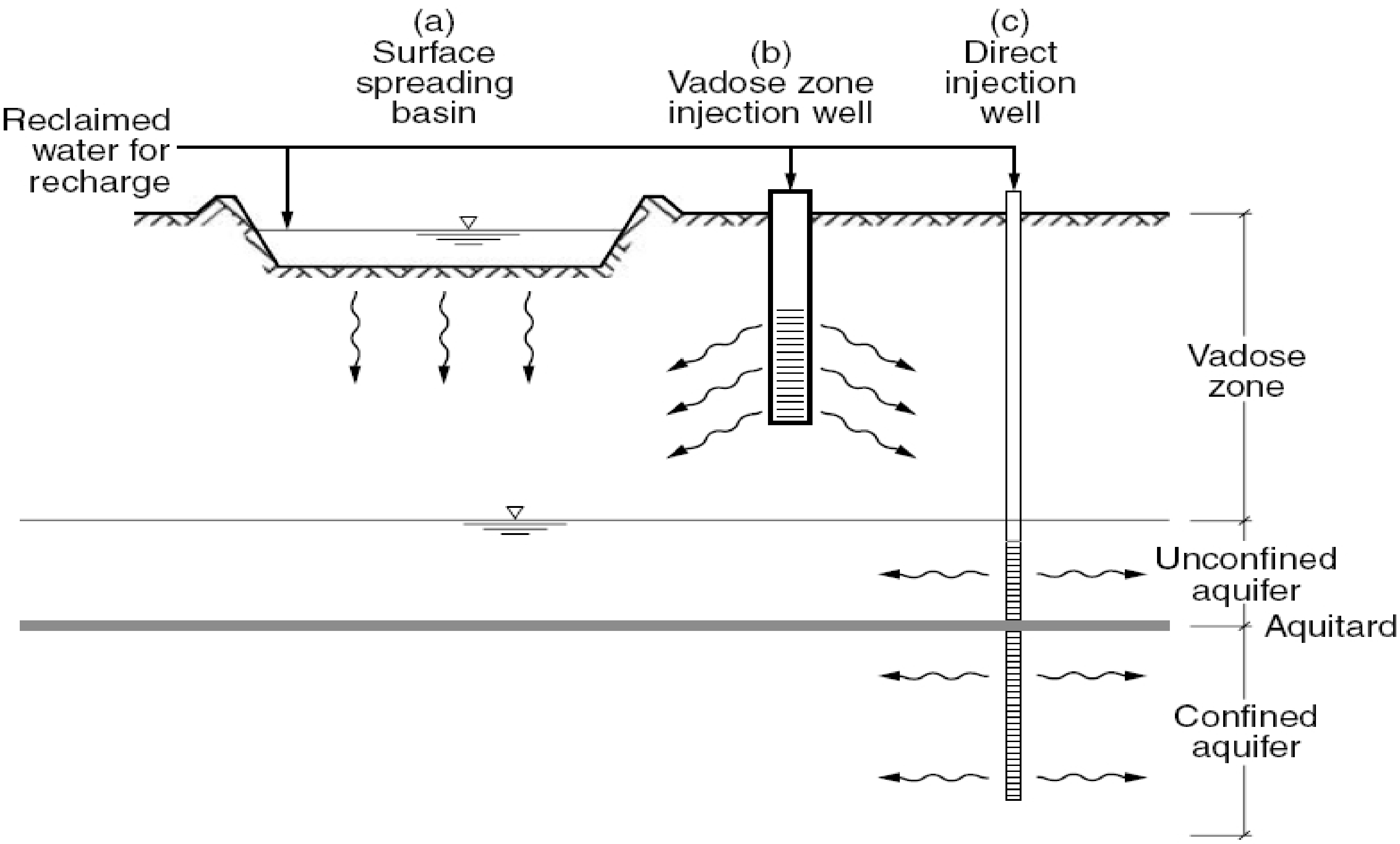
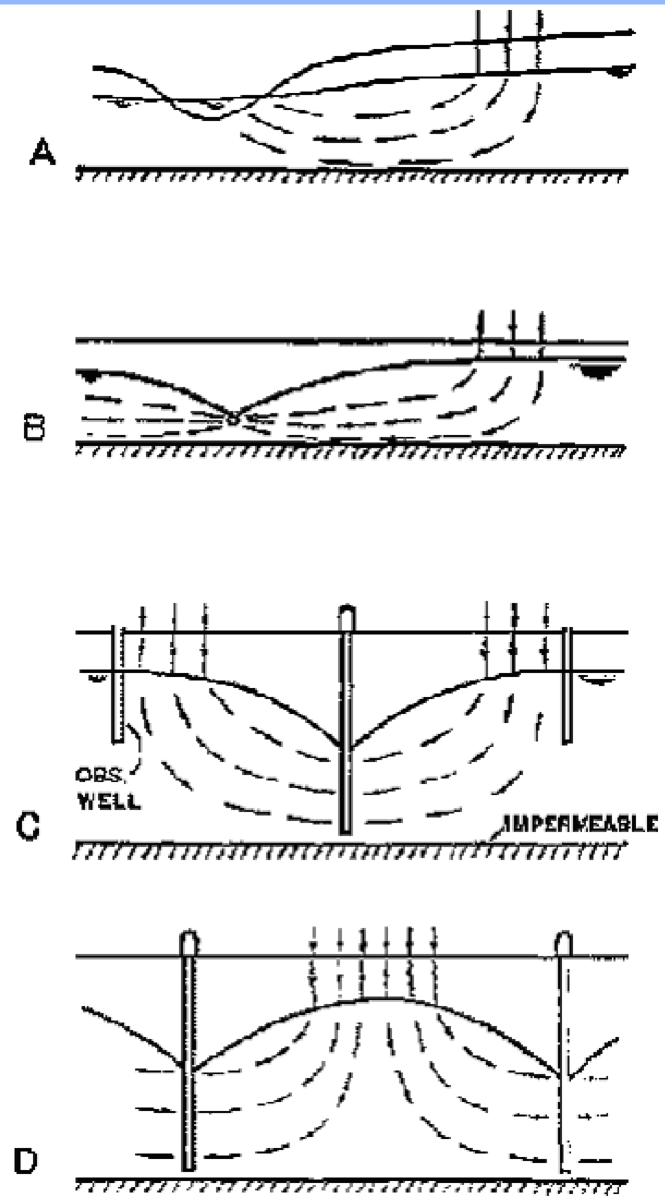



Figure 2 - Source: USEPA (2004)

# Surface Spreading Basins (Infiltration basins)

- Suitable for runoff water as well as for treated effluents that will be reused for indirect potable reuse purposes or agricultural irrigation depending on the degree of purification of the effluents before infiltration

(See schematic of surface spreading SAT systems in Figure 3)




Types of Surface Spreading SAT Systems (Bouwer, 1987)

# Vadose Zone Wells

- Vadose zone wells are boreholes in the vadose zone, usually 10-50m deep depending on the depth of the vadose zone and about 1-2 m in diameter. These wells are used for recharge of unconfined aquifers

- Vadose zone wells are usually used where the surface infiltration is hard due to hydro-geological properties of the soil and where available land is expensive

# Direct Injection Wells

- Used when injecting recycled or reclaimed water directly into deeper aquifer
- Direct injection can be for potable and non-potable reuse but for SAT, this is mostly for non-potable purposes
- Direct injection mostly applied in drought regions where the geological & hydrological conditions do not enable either surface spreading or vadose wells

# Infiltration Rates in SAT

- Performance of SAT systems is affected by different parameters but the influence of infiltration rates is a major parameter.
- Different qualities of wastewater can be infiltered at different velocities depending also on the SAT type.

Other factors influencing Infiltration rates and aquifer treatment are:

1. Soil type and permeability
2. Surface clogging material (the type of wastewater effluents applied)
3. Pond depth
4. Duration of wetting/drying cycles

# Advantages of SAT

- Microbiological: total removal of bacteria and viruses
- Nutrient removal: Very efficient removal of Ammonia, Phosphorus, Carbon
- Very efficient removal of dissolved organic carbon (DOC)
- Efficient removal of micro-pollutants
- Groundwater recharge using the aquifer as storage
- Surface spreading provides added benefits of the treatment effect of soils and transporting facilities of aquifers
- Very efficient removal of organics, nutrients, microorganisms & micropollutants removal completely by natural means

# Limitations of SAT

- Deterioration in the infiltration rate with no ability to recharge all the available effluents
- Due to anoxic conditions, signs of manganese dissolution may appear in the aquifer below the infiltration basins
- Big land requirement
- Clogging in the infiltration interface caused by biological & physical processes
- Chemical process caused by algae photosynthesis change the pH in soil leading to precipitation of carbonate, gypsum, phosphorus, & other chemicals in the soil cause clogging the infiltration area

# Factors affecting Performance of SAT System

- Time and travel distance (Residence)
- Wastewater quality
- Redox Conditions (Oxidation-reduction)
- Maintaining infiltration (Hydraulic loading)
- pH
- Temperature
- Soil Type
- Operating schedule

Table 1 below summarises conditions for different parameters for 3 stages of SAT (Infiltration interface, Soil percolation & GW transport

# Table 1: Comparison of Typical SAT Zones (Amy, 2009)

| Process/ Parameter | Infiltration Interface | Soil - Percolation | Groundwater Transport |
|---|---|---|---|
| Treatment Mechanisms | Filtration√, Biodegradation | Biodegradation√, Adsorption | Biodegradation, Adsorption, Dilution√ |
| Transport | Saturated | Unsaturated | Saturated |
| Residence Time | Minutes | Hours to days | Months to Years |
| Travel Distance | Centimetres/Inches | 3 – 30m /10 – 100ft | Variable |
| Mixing | No | No | Yes (regional G.W.) |
| Oxygen Supply | Recharge Water | Unsaturated Zone | Regional G.W. |
| Biodegradable Org. Carbon Availability | Excess | Excess/Limiting | Limiting |
| Redox Conditions | Aerobic | Aerobic to Anoxic | Anoxic to Aerobic |

# Residence time/travel distance

- Main parameter governing the effluent quality from SAT for all primary, secondary & tertiary effluents

- Sewage water should travel sufficient distance through the soil aquifer & the times in the SAT system should be long enough to produce renovated water of the desired quality

- While 100m underground travel and one month underground retention time is the suggested rule of thumb, the required values depend on the quality of the sewage effluent infiltrating into the ground, the soil types in the vadose zone and aquifer, the depth of the GW, & the desired quality of the renovated water

- Most of the quality improvement takes place in the top 1m of the soil, however, longer travel is desirable because it gives more complete removal of microorganisms and polishing treatment.

# Wastewater (WW) quality

- Quality of WW applied to SAT determines the quality of reclaimed water after soil passage

- Quality also plays a vital role in the performance of the SAT system & in the removal of contaminants

- However, the characteristics of raw wastewater in terms of suspended solids determines the settling efficiency & hence primary clarification to make it suitable for SAT

- Consequently, the application of SE rather than PE is more practical to minimise clogging layer

❖ Pre-treatment of the effluent can help to prevent sedimentation& biofilms formation in the pipelines.

# Redox conditions

- In 1st infiltration stage & passage through the soil interface to the upper layer biofilter, there is enough oxygen but also biodegradable organic carbon & residence time/travel distance in this layer is short

- In vadose zone oxygen is depleted & the residence time/travel distance is longer & most organic matter is biodegraded

- The GW transport stage depends on the recovery well distance from the infiltration point. The mixing ratio with the regional GW determines the chemistry & redox condition. In this stage, the oxic/anoxic conditions may determine the types of micropollutants that will be removed.

# Hydraulic Loading Rate (HLR)

- If the hydraulic loading rate is high, more effluents are infiltered at a given time leaving more relaxation time and oxygen is introduction to the soil.

- However, more organic matter infiltered at a given time may be impairing the bio-activity at the upper layers.

- The longer relaxation time enabling the oxygen introduction is a dominant mechanism.

# SITE SELECTION FOR SAT

- Depths to the groundwater
- Redox conditions
- Soil characteristics
- Groundwater flow pattern
- Proximity to conveyance channel and/or wastewater reclamation facilities

# SAT PLANNING & DESIGN

**SAT Pre-Design Considerations**

1. Intended use of SAT reclaimed water
2. Public health
3. Economic aspects
4. Regulations and guidelines
5. Technical aspects
6. Socio-political aspects
7. Institutional aspects

# SAT PLANNING & DESIGN

**Site Identification and Investigation**

1. Physical factors
   - Land availability
   - Topography
   - Susceptibility to flooding
2. Hydrogeological issues related to SAT operation
   - Depth of vadose zone
   - Soil type
   - Permeability
   - Type of aquifer
3. Land use and location of SAT site
   - Land use
   - Location of SAT site
   - Type of aquifer
   - Soil type
4. Site Investigation
   - Test pits and boreholes

# SAT PLANNING & DESIGN

**SAT Design Considerations**

1. Type of SAT Systems
2. Pretreatment of wastewater effluent
3. Hydraulic loading rate
4. Wetting and drying
5. Spreading basin and layout
6. Groundwater mound
7. Abstraction and monitoring wells
8. Post-treatment of the reclaimed water

# OPERATION AND MAINTENANCE OF SAT SYSTEMS

The SAT system can be divided into 5 parts all which some aspects that need to be kept in a good operational mode:

1. The pumping system & effluent carrying pipe – lines to infiltration fields
2. The infiltration system and SAT system
3. The recovery system
4. The main distribution & storage system (with all seasonal & operative reservoirs)
5. The pumping system after the reservoirs and the distribution system to end-users

(Cikurel & Aharoni, 2006)

# PRE-TREATMENT FOR SAT

Some conditions that can affect the operation of the SAT systems include:

1. Reduction in recharge capacity
2. Bio-fouling of effluent pipelines
3. Clogging as a result of Mn & Fe Oxides

# CONCLUSIONS

- SAT is relatively costs lower than conventional above ground treatment systems
- Operation is simple & no chemical or expensive treatment units & equipment are required
- Supplements existing water sources and replenishes diminishing GW
- Can potentially be applied worldwide depending on geology, soils, hydrology and other appropriate factors

# CASE STUDIES

| Location | Size ($m^3/d$ | End-use | Start up & end of project | Comments |
|---|---|---|---|---|
| Shafdan, Israel | 330,000 | Unrestricted irrigation | 1977 | Surface infiltration of secondary effluents |
| Water Campus, Scottsdale, Arizona, USA | 108,000 | Indirect potable recharge & unrestricted irrigation | 2002 (extension 2008-2012) | Process based on MF/RO and AOP & vadose zone well infiltration |
| Mesa, Arizona | 12,000 | Indirect potable recharge | 1990 | Retention times several days to 5 years |
| West Basin, California, USA | 30,000 | Groundwater recharge | 1997 | Deep bed infiltration of RO prefiltered & AOP polished effluents |

# Reading materials


- Mekorot & UNESCO-IHE (2011) Guidelines for Design & Operation & Maintenance of SAT (and Hybrid SAT) System –- http://www.switchurbanwater.eu/outputs/pdfs/W3-2_GEN_RPT_D3.2.1f-i_Guidelines_for_design_of_SAT_systems.pdf
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- USEPA (2006) Process Design Manual: Land Treatment of Wastewater Effluents. EPA/625/R-06/16. US Environmental Protection Agency, Washington, DC.
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