Assessing the Performance of Channel Purification and Soil Aquifer Treatment for Enabling the Reuse of Treated Wastewater

By

Eng. Maysara Mostafa Ahmed Ghaith

B.Sc. in Water Engineering and Environment- Cairo University

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science
in
Irrigation and Hydraulics Engineering

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Key words:

SAT (Soil Aquifer Treatment), Reuse of Treated Wastewater , Channel purification, Qual2k, Hydrus

Summary:

The reuse of treated wastewater can be enabled by river purification or SAT or both. The performance of the open channel purification system is mainly a function of the travel time. The removal efficiency is found to be about 50-70% for travel time less than 5 days. Also using weirs or drops enhances the reaeration and decreases the wastewater velocity in the channel yielding better purification. For soil aquifer treatment, the concentration of the contaminant is totally removed in the first layer of the soil, which differs from one soil type to another but generally ranges between 3 and 9 m.

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A_c	Cross sectional area (L^2)
a_v	Air content
a_w	Factor representing the quality of waste water
b_k	Empirical coefficient
BOD	Biological oxygen demand (mg/l)
b_w	Factor representing type of weir
c	Concentration (ML^{-3})
C_d	Downstream oxygen level (mg/l)
C_u	Upstream oxygen level (mg/l)
C_∞	Saturation water concentration (mg/l)
CLIMWAT	Climatic database to be used in calculation of crop water requirements, irrigation supply and irrigation scheduling for various crops for a range of climatological stations worldwide.
COD	Chemical oxygen demand
c_r	Concentration of the sink term [ML^{-3}]
C_s	BOD concentration (mg/l)
D	Deficit in the dissolved oxygen (mg/l)
D^g_{ij}	Diffusion coefficient tensor [L^2T^{-1}] for the gas phase
DO	Dissolved Oxygen (mg/l)
D_o	Initial deficit (mg/l)
D^w_{ij}	Dispersion coefficient tensor [L^2T^{-1}] for the liquid phase
E	Longitudinal dispersion (L^2T^{-1}),
EIA	Environmental impact assessment
EPA	US Environmental Protection Agency
f	Self-purification factor
FC	Fecal Coliform
F_{oxc}	Rate at which the decay process decreases when oxygen is almost depleted
g	Solute concentrations in gaseous
H	Water depth (m)
h	Pressure head (m)
HCWW	Holding Company for Water and Wastewater

H_d	Height of step (m)
HEC-RAS	Hydrologic Engineering Centers River Analysis System program
Hydrus2D	Analysis of water flow and solute transport in variably saturated porous media model
K	Hydraulic conductivity (LT^{-1})
Ka	Reaeration rate (T^{-1})
K^A_{ij}	Components of anisotropy tensor while *K* is the unsaturated hydraulic conductivity
k_{dcs}	Decay rate (T^{-1})
K_s	Partitioning coefficient
$k_{s,k}$	Empirical coefficient [L^3M^{-1}]
L_o	Ultimate BOD (mg/l)
m	Empirical coefficient
MWRI	Egyptian Ministry of Water Resources and Irrigation
n	Empirical coefficient
o	Oxygen concentration [mg O2/l]
pH	Numeric scale used to specify the acidity or basicity of an aqueous solution
$Q_{ab,i}$	Abstraction flow at reach *i* (l/d)
Q_i	Flow at reach *i* (l/d)
q_i	Volumetric flux density [LT^{-1}]
Qual2E	Modelling package in the evaluation of a water quality
Qual2k	One-dimensional river and stream water quality model
r	Oxygen deficit ratio
S	Sources and sinks (mg/l/d)
s	Solute concentrations in solid
SAT	Soil aquifer treatment
SS	Suspended Solids
t	Time
T	Water temperature (^oC)
Ta	Air Temperature (^oC)
TSS	Total Suspended Solids
U	Water velocity (m/s)
USAID	U.S. Agency for International Development
V_i	Volume of reach *i* (l)
WASP	Water Quality Analysis and Simulation Program
W_i	External loading of the constituent to reach *i* (mg/d)
WWTP	Wastewater Treatment plant

x	Distance (L)
γ_g	Zero-order rate constants for the gas [$ML^{-3}T^{-1}$]
γ_s	Zero-order rate constants for the solid [T^{-1}]
γ_w	Zero-order rate constants for the liquid [$ML^{-3}T^{-1}$]
η_k	Empirical coefficient [L^3M^{-1}]
μ_g	First-order rate constants for solutes in the gaseous
μ_s	First-order rate constants for solutes in the solid
μ_w	First-order rate constants for solutes in the liquid
ρ	Soil bulk density [ML^{-3}]
θ	Coefficient depending of temperature variation
q_V	Volumetric water content
η	Maximum sorption capacity

Abstract

Water resources in Egypt are limited and population is rapidly increasing. Thus, the gap between supply and demand increases from year to year and as a result water quality is deteriorating. The problem is exacerbated by the development projects at the upper Nile countries with the potential to reduce the already stressed water resources. Seeking alternative resources to compensate for the potential shortage and to help filling the increasing gap between supply and demand; one has to consider the potential of using treated wastewater that is available in large quantities in Egypt.

According to USAID report 2010, wastewater discharge in Egypt amounts to about 9 Mm3/day and only half of this amount was being treated by year 2000. The government is facing a double fold problem of 1) needing to treat the remaining wastewater discharge, and 2) devising a safe mechanism of disposing off the treated wastewater that has a low quality that precludes using it for useful purposes. Therefore, there is a dire need to solve both problems and it would be advantageous to also enable the use of the treated wastewater in a way that contributes to narrowing the gap between supply and demand.

This study uses computer modeling to assess the performance of a system of natural purification of treated wastewater effluent composed of open channel purification, bank infiltration, and soil aquifer treatment. Although the assessment relied on some site-specific data pertaining to 6th October wastewater treatment plant, the assessment is generic in nature and results can readily be generalized to other cases. The modeling of the open channel system is carried out using Qual2k with different wastewater effluent properties, different channel properties and different climatic properties to assess the dependence of the system performance on different regions with different properties. The assessment of soil aquifer treatment (through subsurface filtration) is conducted using Hydrus2D applied to the most critical section.

Based on the simulations and different scenarios, the performance of the open channel purification system is mainly a function of the travel time. The removal efficiency is found to be about 50-70% for travel time less than 5 days. Also using weirs or drops enhances the reaeration and decreases the wastewater velocity in the channel yielding better purification. For soil aquifer treatment, the concentration of the contaminant is totally removed in the first layer of the soil, which differs from one soil type to another but generally ranges between 5 and 10 m.

This system can be used for recharging groundwater aquifers by such purified wastewater, and the stored water can subsequently be used by pumping wells in different agricultural purposes. The results of this study are promising and more elaborated work can be built on these results for the objective of reaching a practical system with multiple benefits.