International Conference "Water, Environment, Energy and Society" (WEES–2009)
New Delhi, 12–16 January 2009

Assessment of Water Quality at RBF Site Haridwar

Aseem K. Thakur[1] and C.S.P. Ojha
Department of Civil Engineering
I.I.T. Roorkee - 247 667, INDIA
E-mail: [1]aseem_thakur@rediffmail.com

Thomas Grischek and Cornelius Sandhu
University of Applied Sciences
Dresden, GERMANY

Ramakar Jha
National Institute of Hydrology
Roorkee - 247667, INDIA

ABSTRACT: Many highly populated cities and towns in India are situated on riverbanks and have favourable hydrogeologic conditions necessary for the natural and cost-effective process of River Bank Filtration (RBF). Two drinking water production wells were selected in Haridwar by the river Ganga to monitor the quality of bank filtrate abstracted in the period 2005–2006. Two monitoring wells were also installed and their water quality was analysed. The physico-chemical instant parameters and turbidity were determined in the field on a monthly basis in pre-monsoon season and every two weeks in monsoon season. The major cations and anions, and bacteriological indicator parameters were analysed in the laboratory. Results show that the parameters investigated for production well water are within permissible limits for drinking water according to WHO and BIS 10500 (1991), except coliform counts. As a result of RBF, total coliforms and faecal coliforms have been removed by 99% to 99.9% respectively in the abstracted bank filtrate. The turbidity is reduced by up to 99.9%. Though during RBF there is an improvement of water quality, it is essential to develop a physical model for the dynamic simulation of flow and transport. The main focus of the applied water quality model has been the dynamic river–aquifer interactions based on the effects of fluctuating river levels. These fluctuations have been relevant for clogging processes as these destabilise the clogged layer. At the RBF site in Haridwar, the extent of clogging is observed to be limited to only few centimetres and water quality simulations indicate a very limited role of the layer in travel zone. However, with the increase in clogged layer, its role on further quality simulation cannot be always over looked.

INTRODUCTION

The potential of RBF systems for the cities along the alluvial banks of the river Ganga in India, where the quality and flow variation in the river water are expected to be significant over the years (Jha *et al.*, 2005) is not yet fully explored. In Europe, the river Rhine water quality had changed from heavily polluted in the beginning of the seventies up to moderately polluted today (Irmscher, 2005). The dynamic behaviour of the Rhine also influences flow velocity and transportation during bank filtration. These fluctuations in travel time and raw water quality are already well known (Eckert *et al.*, 2003). Clogging is still an important factor causing uncertainties in planning stage of river bank filtration plants. Several attempts have been made to develop tools which can predict such process but up till now no such tool has been developed. Based on a lot of experience about clogging from operation of riverbank filtration plants, the hydrological and morphological aspects of river and aquifer have to be analyzed carefully to create a basis for the transfer of available knowledge (Schubert, 2002). Clogging of river bed sediments can be both beneficial in terms of promoting the biodegradation of contaminants but also undesirable in reducing the hydraulic conductivity of the infiltration zone (Hiscock and Grischek, 2002). A stochastic model of particulate transport in a porous medium based on measurable physical and hydraulic characteristics has been developed by Joy *et al.* (1993). The removal of impurities was modelled using slow

[1]Conference speaker

sand filtration with an exponential head-loss development. The relationship between influent (C_0) to effluent quality (C_e) was used, as shown in Eq. 1 (Ojha and Graham, 1994) for,

$$C_e = C_0 \exp(-K\Delta L) \quad \dots (1)$$

where K is the filtration coefficient and ΔL is the depth of the filter bed.

OBJECTIVE

The objectives of the study within the framework of the EU-India River Bank Filtration Network project at Haridwar from 2005–2006 were:

1. Selection of a RBF site in Haridwar, and performing physico-chemical instant parameter measurements in the field and laboratory experiments in pre-monsoon and monsoon seasons to assess water quality changes during RBF,
2. Conducting field experiments related to clogging in the river bed,
3. Development of a model to assess turbidity removal during RBF.

SELECTION OF RBF SITE

A drinking water production well (IW 18) located on Pant Dweep Island in Haridwar and operated by the state water supply organization Uttarakhand Jal Sansthan (UJS) was selected to monitor the quality of bank filtrate abstracted. Two monitoring wells were also installed and their water quality was analysed. On-site field experiments were performed to determine instant parameters such as the temperature of water (T_w), Dissolved Oxygen (DO), electrical conductivity (EC), pH, alkalinity and turbidity on a monthly basis. Major cations and anions, and bacteriological indicator parameters were analysed in the laboratory of the Environmental Engineering Section in the Department of Civil Engineering at the Indian Institute of Technology (IIT) Roorkee, Roorkee. Since the river Ganga and Upper Ganga Canal (UGC) water is snowmelt, it contains low amounts of impurities but the turbidity is an important parameter for water treatment.

BORING OF MONITORING WELLS

Two monitoring wells, MW 1 and MW 2, were bored near production well IW 18 on Pant Dweep. The drilling of MW 1 was done up to 30 m Below Ground Level (BGL) to investigate the sub-surface characteristics. The grain size analysis was done in the Geotechnical Laboratory of IIT Roorkee (Mittal and Ojha, 2005). Then, MW 2 was installed. Since the aquifer material below a depth of 15 m is cohesive in nature, the depth of the well was kept at 16 m BGL. These monitoring wells proved very useful in determining water quality variations throughout the period of the study.

ANALYSIS OF WATER SAMPLES

Table 1 shows the variation of water quality parameters from November 2005 to September 2006. Instant parameters such as T_w, DO, EC and pH have been measured using a portable WTW 350i meter, with one pH sensor and one combined DO and EC sensor. The measurement location was the same at all times, located about 1 m from the banks of the New Supply Channel (NSC) and UGC and at a water-depth of approx. 0.5 m. Turbidity was measured by a HACH instrument and alkalinity by titration method for the various sites of IW 18, MW 1, MW 2, NSC, and UGC.

Table 1: Variation of Water Quality Parameters from November 2005 to September 2006

Parameters	*IW 18*		*MW 1*		*MW 2*		*NSC*		*UGC*	
	Min.	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*
Water temperature (°C)	21.2	23.2	21.3	24.1	22.1	24.3	12.7	21.2	13.4	21.4
Dissolved oxygen (mg/L)	0.3	4.6	0.1	2	0.3	2.3	5.6	9	7.4	9
Electrical conductivity (µS/cm)	394	482	309	399	336	466	131	280	133.1	293
pH	6.5	7.9	6.8	8.1	6.6	8.2	6.9	8.6	7.5	8.6
Turbidity (NTU)	0.2	1.0	0.1	0.8	0.1	0.9	16	2745	17	2775
Alkalinity (mg/L)	158	225	110	225	132	208	32	116	35	109
SO_4^{2-}	23	40	20	52	19	47	19	66	20	72
Total hardness as $CaCO_3$ (mg/L)	13	240	119	214	117	250	57	131	62	150
Total coliform (counts/100 mL)	n.d.	93	n.d.	30	n.d.	75	n.d.	9300	n.d.	1500
Faecal coliform (counts/100 mL)	n.d.	8	n.d.	8	n.d.	23	n.d.	6400	n.d.	7500

In the month of May 2006, the bacteriological investigations to determine total coliforms and faecal coliforms were conducted at the laboratory of the National Institute of Hydrology, Roorkee. The chemical parameters such as total hardness, calcium, magnesium, sodium, potassium, chloride, sulphate and nitrate were analysed by HACH kit (USA). From the month of June 2006 and onwards the physico-chemical investigations were conducted in the Environmental Engineering Section laboratory at IIT Roorkee as per the prescribed methods in the *Standard Methods for the Examination of Water and Wastewater* (Eaton *et al.*, 2005).

RESULTS AND DISCUSSIONS

Variation in Temperature

Pant Dweep island has unconfined strata and it is bounded by the rivers and canals all around. The water present in the unconfined aquifer is riverbank filtered water. So the temperature has to play an important role during the mixing of surface water to the groundwater. The temperature of river or canal water varies as per the season (12.7 to 21.4°C) but the temperature of groundwater varies from 21.2 to 24.3°C. There is a little variation found in groundwater during pre-monsoon season i.e. from 21.2°C to 23°C and during monsoon season groundwater temperature varies from 22 to 24.3°C. The temperature of canal water increases from 12.7°C in November to 21°C in May while during monsoon season the temperature variation is less (18.5°C to 21.2°C).

Variation in Dissolved Oxygen

The Dissolved Oxygen (DO) is an important parameter for the living organisms present in surface water but as the surface water travels through the porous media it decreases as it moves far from the river. During decomposition of organic compounds DO is also utilized thus it is always lower in wells. In pre-monsoon season the DO of well water ranges from 0.4 to 4.7 mg/L, following to a decreasing trend in monsoon season where it varies from 0.25 to 1.1 mg/L. The DO for canal water varies in a cyclic order and it reaches from 8.3 to 9 mg L^{-1} in pre monsoon season while in monsoon season the D.O. varies from 7.9 to 9 mg/L. The mean oxygen concentration in canal water is 8.5 mg/L.

Variation in Electrical Conductivity

Generally the value of Electrical Conductivity (EC) is higher for bank filtrate abstracted from pumping and monitoring wells than in the river or canal water. As the surface water enters in the soil media it dissolves minerals present in the soil. The value of EC varies in a cyclic order ranging from 162 to 280 µS/cm during pre-monsoon season in the UGC and during monsoon season it varies from 131 to 165 µS/cm. In monsoon season the river and canal water is being diluted due to rain water and discharges are always higher and water gets less contact time with the soil, thus the value of EC is less in monsoon season.

Variation in pH

The pH of the water from the pumping and monitoring wells varies from 6.5 to 8.2 during pre-monsoon season and from 7.2 to 7.7 during monsoon season. It varies depending upon the soil matrix through which it travels. The pH of canal water surrounding the island moves in a cyclic order. The pH depends on the discharge of the canal also. During low discharge the pH is higher and vice versa. The pH of the canal in the pre-monsoon season varies from 7.2 to 8.6. In monsoon the variation is from 7.5 to 8.2. All the pH values lie within the permissible range for drinking water.

Variation in Alkalinity

The alkalinity of water is its acid neutralizing capacity. The pumping and monitoring wells have higher alkalinity because when water passes through the soil matrix it dissolves carbonates and bicarbonates. During pre-monsoon season it was stable from November 2005 to March 2006 and then it started decreasing till May 2006 but thereafter, during the monsoon season, it has varied in an increasing manner. The canal has low alkalinity but it has a high variation from 116 to 54 mg/L and during monsoon it has further has decreased down to 32 mg/L in June and then started increasing and achieved a maximum value of 95 mg/L in September 2006.

Variation in Sulphate

The sulphate concentration shows very little variation, both in case of well water and canal water. The average sulphate concentration in the pre-monsoon season in well water is 25 mg/L and during monsoon season it is observed to be 28 mg/L.

Variation in Total hardness

Total hardness is an important parameter which is the sum of calcium and magnesium concentrations expressed as calcium carbonate hardness in mg/L. During the pre-monsoon season there is little variation in well water but during monsoon season it has decreased slightly but the variation is low. In case of canal water, the total hardness decreases during the monsoon season.

Variation of Total Coliforms

The total coliform present in water from monitoring well 2 is higher in the months of November 2005, and in 2006 in March and May. In other months it was found within the permissible range. The water from wells IW 18 and MW 1 have generally total coliforms within the permissible range. The difference is because of the open land in the vicinity of IW 40 and MW 2. Due to a heavy rush of pilgrims on religious occasions, the open land is used for defecation. The faecal bacteria and micro-organisms infect the shallow groundwater in the unconfined aquifer. Since Haridwar is a place of religious importance, many pilgrims bathe in the UGC. The UGC and NSC are contaminated with total coliforms whose concentration is higher in low-flow conditions. During high-flow conditions (June–July), the total coliforms are less in canal water.

Variation of Faecal Coliforms

It is observed that water from MW 2 contains faecal coliforms during some months. This could be due to the open land near MW 2 (as described in previous paragraph) that is used by tourists and pilgrims to defecate. Since the groundwater depth is shallow (3 m BGL), the pathogenic bacteria may contaminate the pumping and monitoring wells in the vicinity. The canal water is highly contaminated (as shown in Figure 1), but due to RBF the pumping and monitoring wells have less faecal coliforms. Thus it is observed that RBF plays a significant role in removing faecal coliforms.

DISCHARGE AND TURBIDITY OF CANAL WATER

Monitoring of discharge of the canal and turbidity was observed for more than one and half years. Discharge and turbidity in any canal or river are interrelated with time as shown in Figure 2. It is observed that during the monsoon season the discharge is high and the canal water carries a high load of suspended matter and fine sediments which increases turbidity.

A graph between turbidity and discharge has been plotted and it has been observed that turbidity increases exponentially with increase in discharge, as shown in Figure 3. The pumping action adjacent to the canal causes effective stress in the canal bed and a hydraulic gradient is generated due to which water present in the canal bed is bound to enter into the aquifer. With water, fine sediments also enter into the porous media which can cause clogging of the canal bed.

CLOGGING TESTS IN THE CANAL BED

Clogging tests were conducted in the NSC and UGC in March 2007 at various places to study the clogging of the canal bed. The research findings are mentioned below:

1. It was observed that the canal beds were clogged not more than 5 cm,
2. The clogging layer can be crucial if remains stable,
3. However, due to diurnal fluctuations in the discharge of the canal, the clogging layer is prone to destabilisation or destruction.

In case of RBF, the river water as influent quality (C_0) and river bank filtrate as effluent quality (C_e), and the distance between river to RBF well (L), Eq. 2 will hold

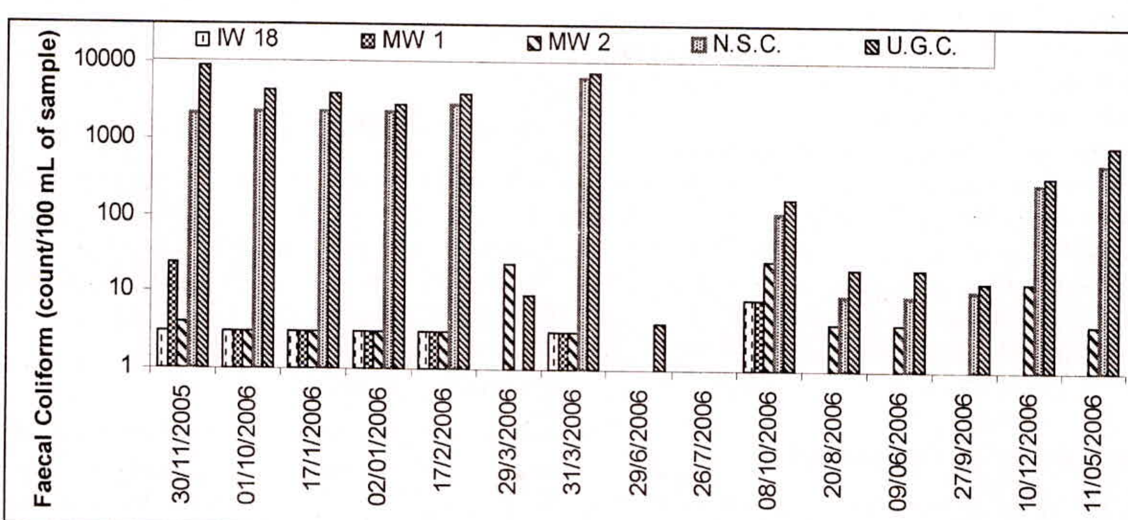

Fig. 1: Faecal coliforms in river water and bank filtrate, November 2005–September 2006

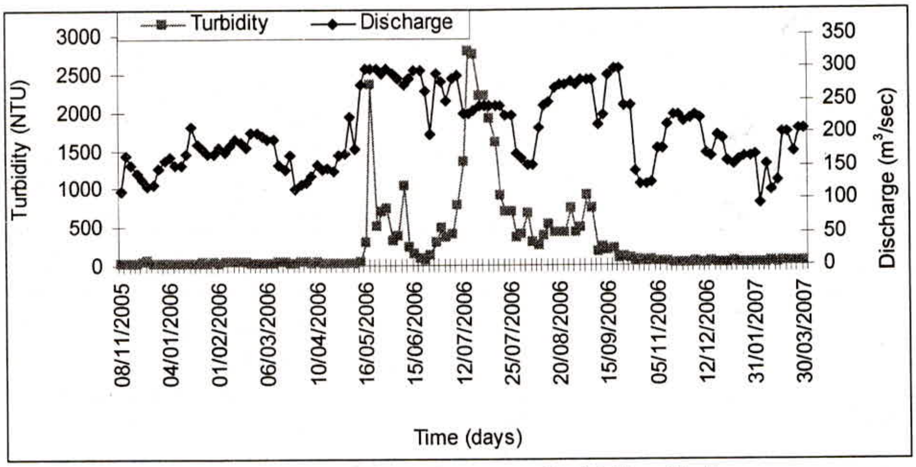

Fig. 2: Variation of discharge and turbidity with time

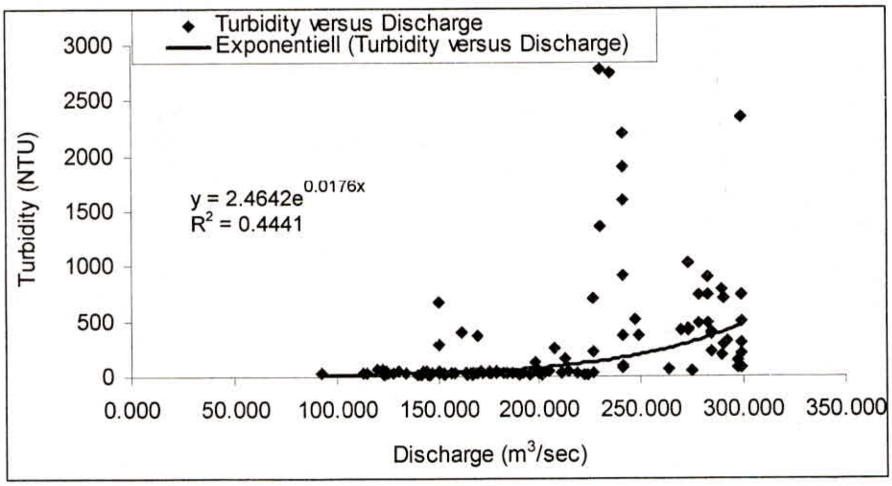

Fig. 3: Variation of turbidity with discharge

well when the clogged layer is insignificant (Ojha and Graham, 1994)

$$C_e = C_0 \exp[-\lambda_0 L] \quad \dots (2)$$

Where λ_0 is the clean bed filtration coefficient, the bracket term in Eq. 2 is dimensionless. It seems from the above equation that the filtration coefficient is an important parameter relating river bank filtrate and river water. The assumption regarding applicability of Eq. 2 is valid as the resultant shear stress acting on the river bed is more than the critical shear stress for most part of the day due to variation of discharge in a canal and as a result the clogged layer seldom stabilizes.

VARIATION OF FILTRATION COEFFICIENT WITH INFLUENT QUALITY

The filtration coefficient is a very important factor in RBF. An attempt has been made to study the variation of the filtration coefficient depending on turbidity. The variation of filtration coefficient with influent quality is shown in Figure 4.

The variation for the filtration coefficient in respect of variation of turbidity is shown in Figure 5. It can be seen that the variation of the filtration coefficient in respect of varying influent water quality can be described satisfactorily using the following equations.

For turbidity model, $R^2 = 0.88$, the filtration coefficient,

$$\lambda = 0.0084 \ln(C_0) + 0.0115 \quad \dots (3)$$

SIMULATION OF EFFLUENT WATER QUALITY

Using the above mentioned equation Eq. 4 can be written for computing the effluent water quality such as turbidity which is shown in Figure 6. For turbidity,

$$C_e = C_0 \exp\left[-\left\{0.0084 \ln\left(C_0\right) + 0.0115\right\} L\right] \quad \dots (4)$$

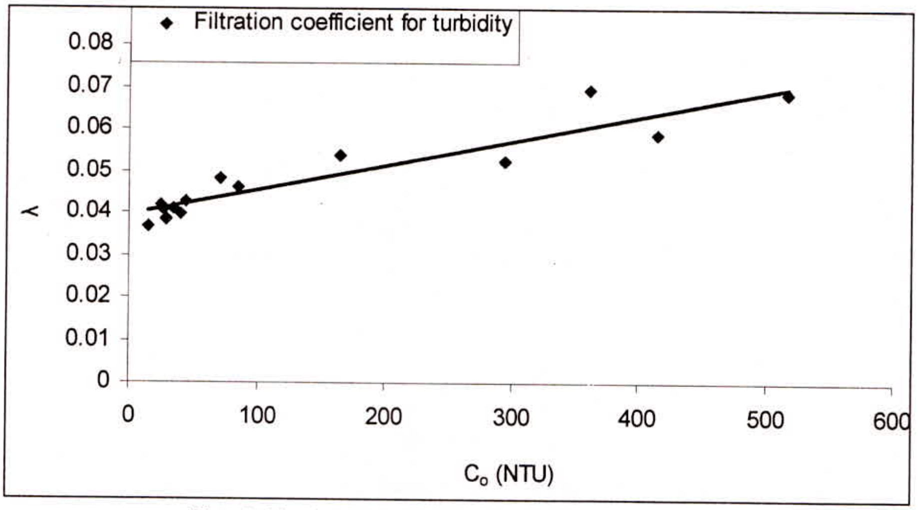

Fig. 4: Variation of filtration coefficient with ln C_0

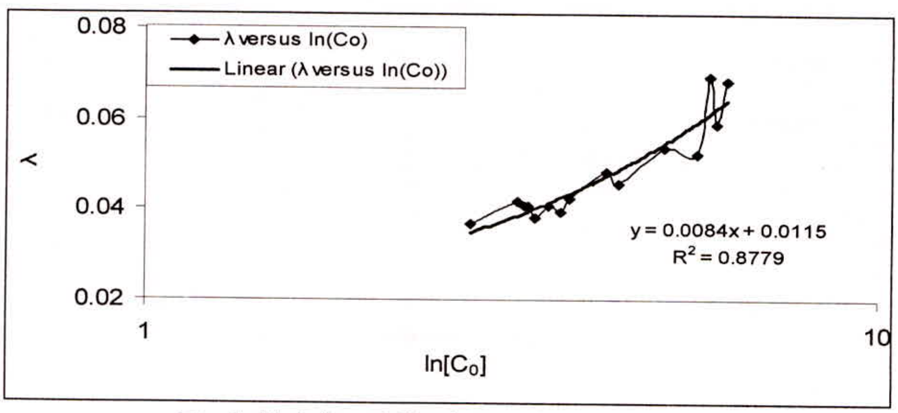

Fig. 5: Variation of filtration coefficient with ln C_0

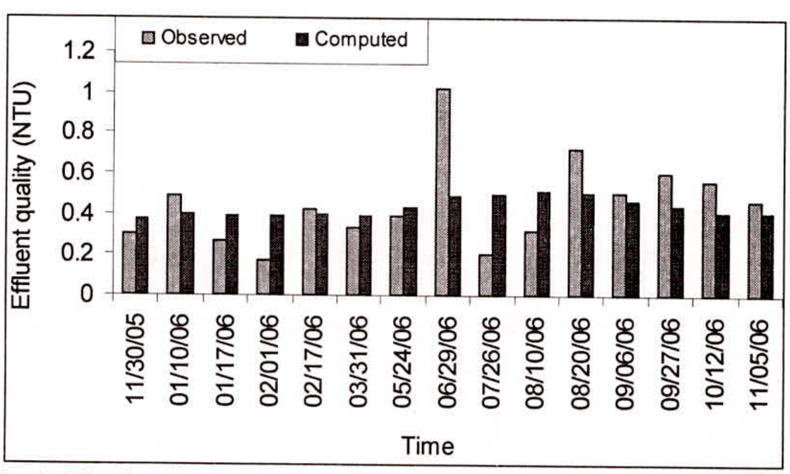

Fig. 6: Simulation of observed and calculated effluent quality versus time

CONCLUSIONS

Based on an assessment of water quality at the RBF site in Haridwar, the following conclusions can be made:

- The removal of total coliforms and faecal coliforms is observed up to 2 log during RBF.
- Due to RBF, there is a distinct reduction in turbidity. Turbidity may cause clogging of the river bed if the clogging layer is not prone to destabilising factors.
- The applied water quality model using a filtration coefficient and the distance between river and the

point of filtrate quality has to be improved to reflect the observations.

- At the RBF site on Pant Dweep, the clogged layer seems to be insufficiently developed to have any significant influence on the modelling of effluent quality for a given influent quality. However, it is noted that this condition may not be always encountered at other RBF sites.

ACKNOWLEDGEMENTS

This study was an activity of the EU-India River Bank Filtration Network project funded by the European Union's Economic Cross Cultural Programme (ECCP). It was also funded by the Indo-German DST-BMBF project IND 05/014.

REFERENCES

Bureau of Indian standards (2003). "Drinking Water—Specification (First Revision) IS10500:1991, Incorporating Amendment Nos. 1 & 2". Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi - 110 002.

Eaton, A.D., Clesceri, L.S., Rice, E.W., Greenberg, A.E. and Franson, M.A.H. (eds) (2005). Standard Methods for the Examination of Water & Wastewater: Centennial Edition. American Public Health Association.

Eckert, P., Rohns, H.P. and Irmscher, R. (2003). "Periodische Schwankungen hydrogeochemischer Prozesse bei der Uferfiltration (Periodical fluctuations of hydrogeochemical processes during bank filtration)", ARW Jahresbericht 2003.

Hiscock, K.M. and Grischek, T. (2002). "Attenuation of groundwater pollution by bank filtration". J. Hydrol., 266(3–4), 139–144.

Irmscher, R. (2005). "Background and experiences in riverbank filtration in Germany". J. Indian Wat. Res. Soc., 25(2), 55–58.

Jha, R., Ojha, C.S.P. and Sharma, K.D. (2005). "Evaluation of riverbank filtration potential for selected cities in the Ganges plains". J. Indian Wat. Res. Soc., 25(2), 25–30.

Joy, D.M., Lennox, W.C. and Kouwen, N. (1993), "Stochastic Model of Particulate Transport in Porous medium", Journal of Hydraulic Engineering, 119(7), 846–861.

Mittal, S. and Ojha, C.S.P. (2005). "Report on Soil Investigations for Hydraulic Study in Haridwar", internal report: EU-India River Bank Filtration Network project, Department of Civil Engineering, Indian Institute of Technology Roorkee, 1–12.

Ojha, C.S.P. and Graham, N.J.D. (1994). "Prediction of deep-bed-filter performance using recursive algorithms". J. Env. Engrg., ASCE, 120(4), 961–971.

Schubert, J. (2002). "Water-quality improvements with riverbank filtration at Duesseldorf Waterworks in Germany". In: Ray, C., Melin, G., and Linsky, R.b. (eds) *Riverbank Filtration: Improving Source Water Quality.* Kluwer Academic Publ., Dordrecht, The Netherlands, 267–277.

World Health Organization (1993). "Guidelines for drinking water quality". 2nd ed., Vol. 1, Geneva, 188.