

Assessing Spatio-Temporal Variability of Inflow and Infiltration in Sewer System Under Different Soils

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Abstract

The additional waterflow, due to groundwater and/or rainwater inflow and infiltration (I&I), into a wastewater treatment plant (WWTP), expected to be used for irrigation, is a growing concern, as the I&I can contribute a significant proportion of the total flow (sanitary flow plus I&I) entering WWTP, while in general only the sanitary flow is monitored. In other words, both sanitary flow and I&I monitoring is a must to accurately calculate total treated wastewater availability for irrigation planning. The I&I is an unavoidable problem and is associated with soil types. The two objectives of this paper are: i) to investigate the impact of soils on I&I under wet weather and dry weather conditions; ii) to estimate the proportion of I&I in total wastewater (wastewater and excess groundwater/rainwater). To cover different soils, wastewater flow and rainfall were monitored at the entrance of five WWTPs selected from five towns of Rangitikei District Council in New Zealand: Bulls, Marton, Hunterville, Mangaweka and Taihape. Soil information was collected from S-map which is a digital soil map for New Zealand. Asset Monitoring Ltd. was engaged to monitor wastewater flow by installing "in-pipe" flow meters in the incoming mains (inlet into a manhole) and recording the effluent flows every five minutes. Rainfall was monitored by installing a tipping bucket rain gauge in each town and recording rainfall every two minutes. Height/Velocity/Quantity (HQV) methodology was adopted as being the best solution for estimating wastewater depth, velocity and quantity for all flow monitoring locations. Manual depth and velocity calibrations was conducted during the monitoring period for different flow regimes for data accuracy. Wastewater flow and rainfall data were analysed for each town to investigate spatial and temporal variability in I&I measurements, enabling to correlate I&I with different soils. The methodology recommended by the Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection was adopted to divide the total effluent flow in four distinct components: i) sanitary flow; ii) groundwater infiltration; iii) directly discharged rainwater; iv) rain-induced infiltration. Total treated wastewater volume comprising wastewater and excess rainwater was assessed, which contribute to improved irrigation planning, and eventually supporting water conservation.

Keywords: Inflow and Infiltration, Wastewater, Irrigation, Groundwater, Rainwater, Soil, New Zealand.

Introduction

Wastewater is water generated after the use of freshwater in different applications such as domestic, industrial, commercial or agricultural activities [1]. Based on its origin, wastewater

is classified as domestic, industrial and commercial. Domestic wastewater is generated from residential sources such as toilets, sinks, bathing, and laundry. Industrial wastewater comes from manufacturing facilities such as factories or plants. Commercial

wastewater comes from offices, hotels, stores and other enterprises. Municipal/urban wastewater is a mixture of domestic, industrial and commercial wastewater (Ibid, 2010). A network of pipe systems that takes wastewater from a property, transmit to the treatment plant and then discharge into the surrounding water body is combinedly known as wastewater network. In a treatment plant, contaminants are removed using various pro-

cesses like screening, coagulation, clarification, filtration, and disinfection to ensure water is safe for reuse. Globally, there are practices of wastewater reuse for various purposes. The detailed information related to the utilization of treated wastewater has been described in [2]. Some of the major sectors reusing wastewater around the world are shown in Figure 1.

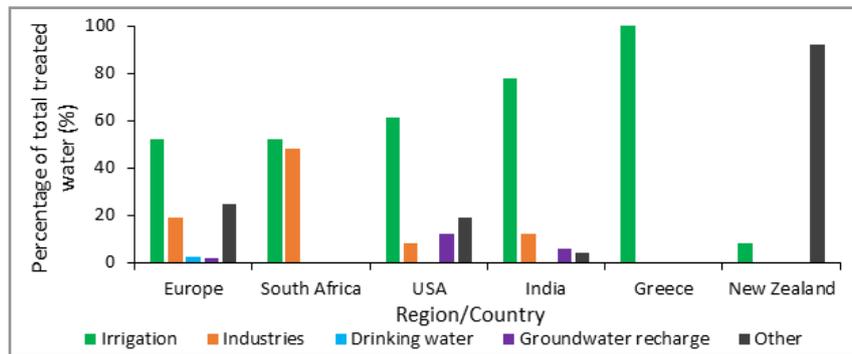


Figure 1: Major Sectors Reusing Water in Different Regions/Countries Sources: [3-12].

Treated wastewater is reused in four main areas: irrigation uses, industrial uses, groundwater recharge and other different uses including portable water supply [13]. These four major sectors receiving treated wastewater are discussed further below, with focus on irrigation use.

Treated Wastewater In Irrigation Uses

Irrigation is by far the largest user of treated wastewater. For example, in Greece 100% and in Israel 90% of the treated wastewater is used in irrigation [14]. Treated wastewater use in irrigation is more common in water scarce areas such as in South Africa and Europe where reliable and adequate quantities of freshwater are lacking while its demand is increasing [7,15]. [16] reported that 40% of the global population is situated in heavy water-stressed basins, which represents the water crisis for irrigation. Therefore, interest in the reuse of wastewater for irrigation is increasing in arid areas of South Africa especially Western Cape Province [15,2]. Irrigation application of treated wastewater is also common in some middle-income countries, such as Tunisia, Jordan and Saudi Arabia [16-21]. Wastewater reuse in irrigation is an ideal resource to replace freshwater use in agriculture [22]. Treated wastewater use in agriculture has been found a more applicable and ecofriendly option [2]. At global level, treated wastewater irrigation supports agricultural yield and the livelihoods of millions of smallholder farmers [19]. Treated wastewater contains valuable nutrients, such as phosphorus, nitrogen, potassium, and sulphur required by the plants. Therefore, treated wastewater use in irrigation reduces the use of fertilizers, improves soil fertility, increases crop productivity and decreases the cost of crop production. However, if irrigation is meant to be with treated industrial wastewater, advance wastewater treatment [2] is essential because it may contain heavy metals (i.e. Cu, Cr, Mn, Fe, Pb, Zn, and Ni) which are non-biodegradable [23]. These heavy metals accumulate in topsoil (at a depth of 20 cm) enter the human and animal body through leafy vegetables consumption [24]. In contrary to use of treated wastewater in irrigation, use of untreated wastewater in agriculture may cause serious environmental and public health concern (health concern for farmers, who are working in wastewater-irrigated

fields). Despite this fact, many low-income countries in Africa, Asia and Latin America use untreated wastewater as a source of irrigation [25]. A brief discussion on the risk associated with untreated wastewater use has been described in [2]. If 100% of the treated wastewater is discharged to land, we will need massive storage facilities for wastewater, which may not be feasible or affordable. Therefore, treated wastewater needs to be used in multiple sectors including irrigation and industrial uses.

Treated Wastewater in Industrial Uses

Treated wastewater reuse in industrial activities is another application that does not require drinking water quality [13]. The suitability of reclaimed wastewater use in industrial activities depends on the particular purpose, and accordingly different purification grades are required. Some of the industries that can benefit from wastewater reuse include manufacturing, power generation, textile, drilling. Industrial activities receiving treated wastewater include equipment cleaning (vehicle washing), rinsing operations, boiler feedwater, certain stages of production. It is also used for cooling purposes in thermal power plants, toilet flushes, firefighting and building construction activities [2].

Treated Wastewater in Replenishing Groundwater Aquifers

Treated wastewater is used to replenish depleted and overexploited groundwater aquifers by injecting it into the ground. In coastal areas, it is used to recharge groundwater aquifers to prevent the intrusion of saltwater, which occurs when groundwater has been over pumped [26]. This process of injecting wastewater into an aquifer acts as a source of artificial recharge to augment existing water supplies. This can be considered as one of the sustainable water management strategies, especially in dry regions facing water scarcity.

Treated Wastewater in Potable Water Supply

In some countries including Singapore, Australia and Namibia, and some states in USA such as California, Virginia and New Mexico, purified wastewater is added to the potable water supply directly [26]. However, this is a very rare practice [27]. Most successful projects are non-potable wastewater reuse schemes

- where purified water is placed into an environmental buffer before entering a drinking water distribution system [27]. Recycled water that ends up in drinking water would have to undergo extensive and thorough purification.

Treated Wastewater Disposal to Waterways

In many parts of world, treated wastewater is discharged to waterways. For example, in Marton, a town in Rangitikei District Council (RDC), currently treated wastewater is discharged into Tutaenui Stream, which in summer is primarily treated wastewater due to its lowered flows. Recycled water discharge into waterways replenishes sensitive ecosystems where wildlife, fish and plants are left vulnerable when water is diverted for urban or rural needs [26]. Treated wastewater disposal to waterways has positive implications, while untreated wastewater disposal to waterways is associated with a number of environmental problems. Therefore, it is a frequent topic of conversation, which isn't positive. For example, in New Zealand, Tangata whenua advocate for wastewater not to enter surface water. Nevertheless, in many countries' wastewater is directly discharged to rivers/streams without treatment. For example, in India, currently only 37.6% of the urban wastewater is getting treated [28]. In Nepal, almost all wastewater is discharged to rivers without any treatment. Releasing wastewater in rivers, agriculture land, and soils without any treatment has detrimental effects on waterways and public health [2]. Use of treated wastewater can play a vital role to combat water scarcity. However, in New Zealand including in RDC, almost all treated wastewater goes to the ocean and rivers without any productive use. There is anecdotal evidence and some historic records of high inflow/infiltration (I/I) in a number of the wastewater networks in RDC [29]. Several networks have capacity constraints in localised areas that have

resulted in historic wastewater spilling and overflows during high rainfall events. Existing wastewater networks are too old, thus limiting their capacity and performance for safe passage of wastewater from a property to a discharge point [30]. For example, in Marton of RDC, the oldest parts of the network were built around 1910. In another town Bulls of the RDC, the oldest parts of the network were built in 1974. Existing wastewater treatment plants in both towns have reached their economic and operational life expectancy and need upgrading as they are ineffective in producing treated wastewater to meet the requirements. Evaluation of existing wastewater networks and investigation of options to utilise treated wastewater can contribute to wastewater management [31].

Therefore, RDC aims to quantify I/I and utilise wastewater in irrigation to reduce wastewater treatment load. This approach can potentially save water for other users, including irrigation. In the same vein, this paper aims at addressing two objectives: i) investigating the impact of soils on I&I under wet weather and dry weather conditions; ii) estimating the spatio-temporal variability of inflow/infiltration (I/I) in total wastewater (wastewater and excess groundwater/rainwater). Findings from the study will eventually contribute towards sustainable wastewater management in New Zealand and beyond.

Methodologies

Study area

To cover different soils, wastewater flow and rainfall were monitored at the entrance of five Wastewater Treatment Plants (WWTP) selected from five towns in the Rangitikei District: Bulls, Marton, Hunterville, Mangaweka and Taihape (Figure 2).



Figure 2: Study Area (Rangitikei District and Its Five Towns Used For The Study)

Instrument Set-Up for Wastewater Depth and Flow Rate Calculation

Asset Monitoring Ltd, Waihi Beach, New Zealand was engaged to monitor in-pipe depth, velocity and quantity for each flow monitoring location. Height/Velocity/Quantity (HQV) “in-pipe” flow monitoring methodology was adopted for the study. Figure 3 shows the instrumental set-up adopted. Required instruments were prepared in three steps as explained below:

Step 1: One open channel “in-pipe” flow gauges (flow meter)

with pressure and velocity sensors was mounted on a poly band and prepared a circular shape to suit the pipe diameter.

Step 2: The “in-pipe” flow gauge was installed in the incoming mains (inlet into a manhole), positioning as close as possible to the pipe invert. The flow gauge was installed in such a way that the sensor could be used also for manual calibration.

Step 3: The “in-pipe” flow gauge was connected with a logger to record flow data.

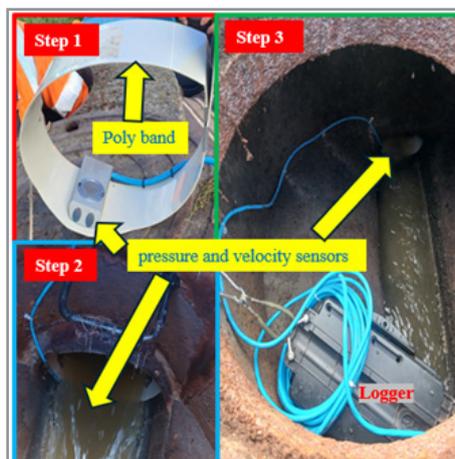


Figure 3: Instrumental set-up adopted to calculate water depth and flow rate

The flows were recorded every five minutes. All monitors were pre-calibrated, and bench tested prior to installation. In addition, manual calibrations for depth and velocity were conducted during the monitoring period at different flow regimes for data accuracy.

Instrument Set-Up for Rainfall Monitoring

Rainfall was monitored by installing tipping bucket rain gauges in each town (Figure 4). Rainfall was recorded at every two minutes interval.



Figure 4: Instrumental set-up for rainfall monitoring

Separating Total Effluent Flow Into Distinct Components

The methodology recommended by the Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection was adopted to divide the total effluent flow in four distinct components: i) sanitary flow; ii) groundwater infiltration; iii) directly discharged rainwater; iv) rain-induced infiltration. These four components have been defined as below:

Sanitary flow: The difference between the total Dry Weather Flow (DWF) and the night flow (0 and 6 A.M.) for the same period. The DWF is defined as the wastewater when there are no rainfall events which consist of groundwater infiltration and sanitary flow. Groundwater infiltration (GWI): 80% of the night flow (0 and 6 A.M. during dry weather) when sanitary flow is negligible, considering 20% industrial wastewater.

Direct rainwater flow (DRF): Flows that enter the network when a rainfall event begins and ends when the rain stops.

Rain-induced infiltration: Flows during the instant when the rainfall event ends until it reaches to DWF again.

Results and Inference

Identifying dry and wet periods

Dry Weather Periods (DWP) and Wet Weather Periods (WWP) were investigated by analysing rainfall events. The period preceded by 3 days without rainfall was termed as DWP while the period with a rainfall event was termed as WWP. Figure 5 shows DWP and WWP for Marton. Wastewater flows measured during those periods were analysed.

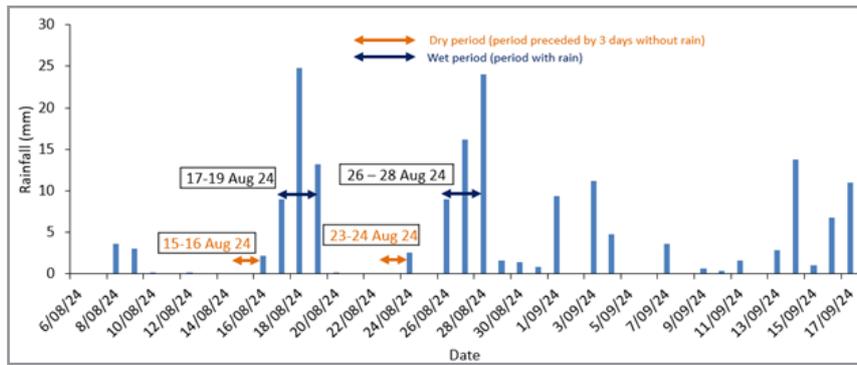


Figure 5: Dry and Wet Periods in Marton

Quantifying Four Distinct Components of Total Effluent Flow

The wastewater flow and rainfall hydrograph in Figure 6 give a schematic representation of four distinct components of the total effluent flow in Marton.

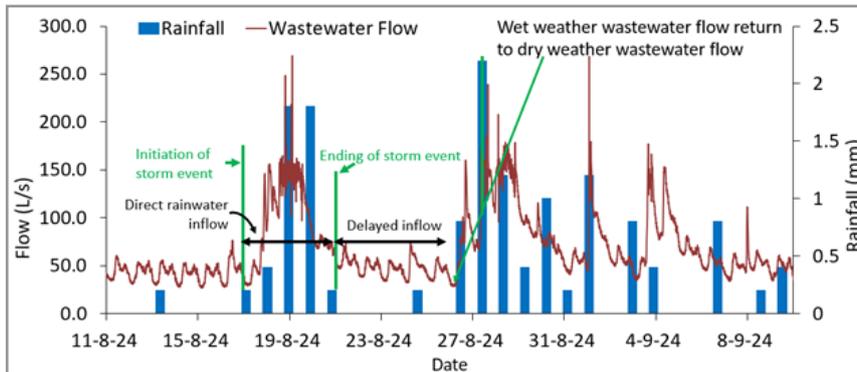


Figure 6: Wastewater Flow and Rainfall Hydrograph in Marton

As it can be seen in Figure 7, only 14% of the total wastewater (TW) comprises of sewer wastewater (SF); 10% is contributed by rain induced infiltration (RII), around 25% is contributed by

the groundwater infiltration (GWI), and almost 50% is contributed by direct rainwater inflow (DRW).

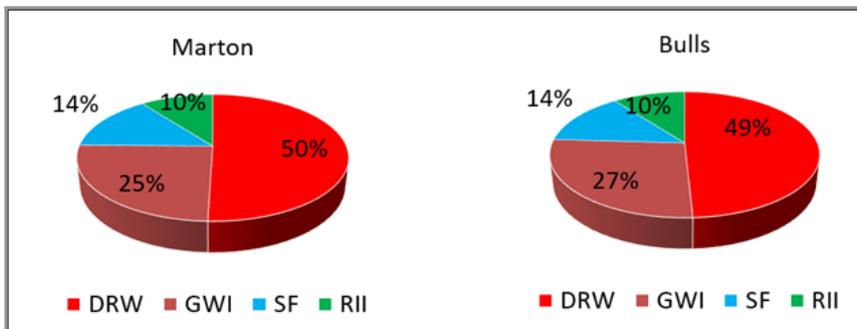


Figure 7: Four distinct components of the total effluent flow in marton and bulls

Impact of Soil Saturation on Dry Weather Flow (DWF)

Average hourly DWF was plotted for two dry periods against the data measured in Marton and Bulls (Figure 8). DWF for the first period has been represented as DWF I and that for the second period is represented as DWF II. There was higher rainfall pre-

ceding DWF II compared to DWF I. Therefore, for both towns, DWF II is larger (11%) than DWF I, due to the saturation of the soil causing more infiltration in the DWF II period. This implies, the higher the soil saturation, the higher will be the groundwater infiltration.

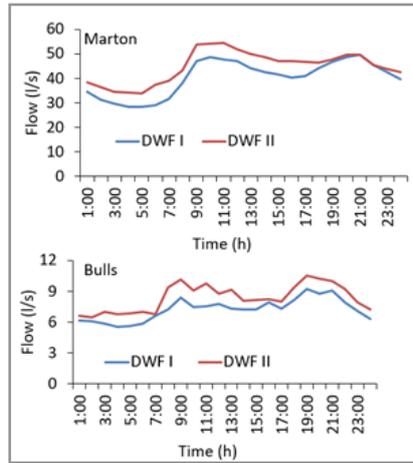


Figure 8: Average hourly dwf for two dry periods in Marton and Bulls

Impact of Soil Types on DWF

Figure 9 shows the wastewater networks and soil types around the wastewater networks in Marton and Bulls. As it can be seen,

in Marton soil around the wastewater network is draining, while in Bulls it is well-draining or poorly draining.

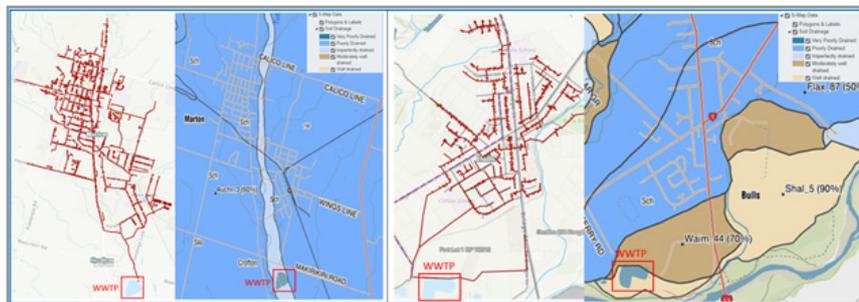


Figure 9: Soil Types Around Wastewater Network in Marton and Bulls

The soil types have a clear impact on wastewater flow after rainfall (Figure 10). Compared to Bull, the soil in Marton is more

clayey with low permeability thus releases water slowly. Therefore, wastewater after rain drops slowly.

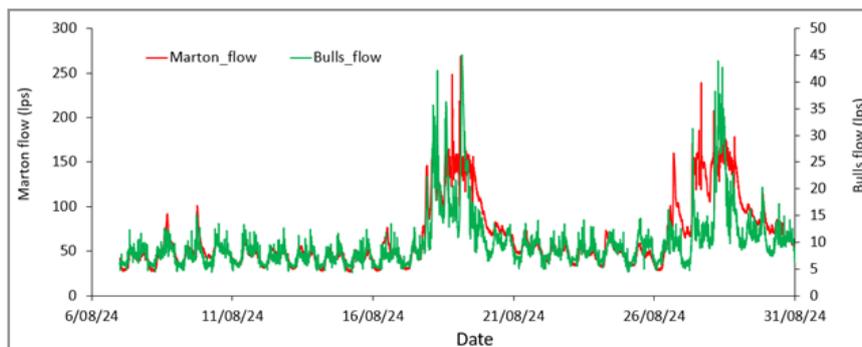


Figure 10: Wastewater Flow in Marton and Bulls After Rain Event

Conclusions

Based on the results the following conclusions have been drawn:

- Soil saturation plays a key role in groundwater infiltration, the higher the soil saturation, the higher will be the groundwater infiltration;
- During studied rain time, only 14% is domestic wastewater, and the remaining 86% were undesirable volumes. Of these, 25% were infiltration flows, and 61% were rainwater flows;
- Findings are in line with the findings by Isabel et al. (2022) who found 15% domestic wastewater, and the remaining 85% undesirable volumes, during studied rain time.

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