TEMPORARY STORAGE MODELLING FOR AN EFFLUENT IRRIGATION SCHEME

W.J. McKenzie, R.A. Docherty, B. Harding
Pattle Delamore Partners Limited, Auckland, New Zealand

ABSTRACT

The townships of Waipukurau and Waipawa in Central Hawke's Bay currently discharge treated municipal wastewater effluent to the Tukituki and Waipawa rivers respectively. The two rivers merge downstream of the two townships, where the Tukituki name remains. The Tukituki river is of high amenity value, being the most frequently fished river in the region and is popular for public recreation. For this reason Central Hawke's Bay District Council (CHBDC) and Hawke's Bay Regional Council (HBRC) are working collaboratively to significantly improve the water quality of the affected rivers.

A new scheme is proposed to remove a large portion of the effluent entering the rivers and irrigate it to two large parcels of land. The scheme requires buffer storage to store wastewater when the capacity of the dual discharge (to land and river) is exceeded by the inflow of wastewater.

This paper describes the development of a water balance model which determines storage requirements for the buffer ponds. To provide confidence in the selected storage values, the model has been run using 22 years of data.

The model shows high sensitivity of required storage; with the volume of temporary storage being dependent primarily on the limited discharge capacity to the rivers during March till June. Approximately 50% of the effluent will be applied to land, with the remaining effluent being targeted to enter the river at times of minimal environmental impact.

KEYWORDS

Effluent, Tukituki, discharge, irrigation, wastewater, storage, water balance

1 INTRODUCTION

Central Hawke's Bay District Council (CHBDC) currently has resource consent to discharge municipal wastewater from the Waipawa and Waipukurau townships to the Waipawa and Tukituki rivers respectively. This consent requires an upgrade in the standard of the treatment, and improvement in quality, of the effluent by 2014. In particular, the concentration of dissolved reactive phosphorus in the effluent is to be significantly reduced.

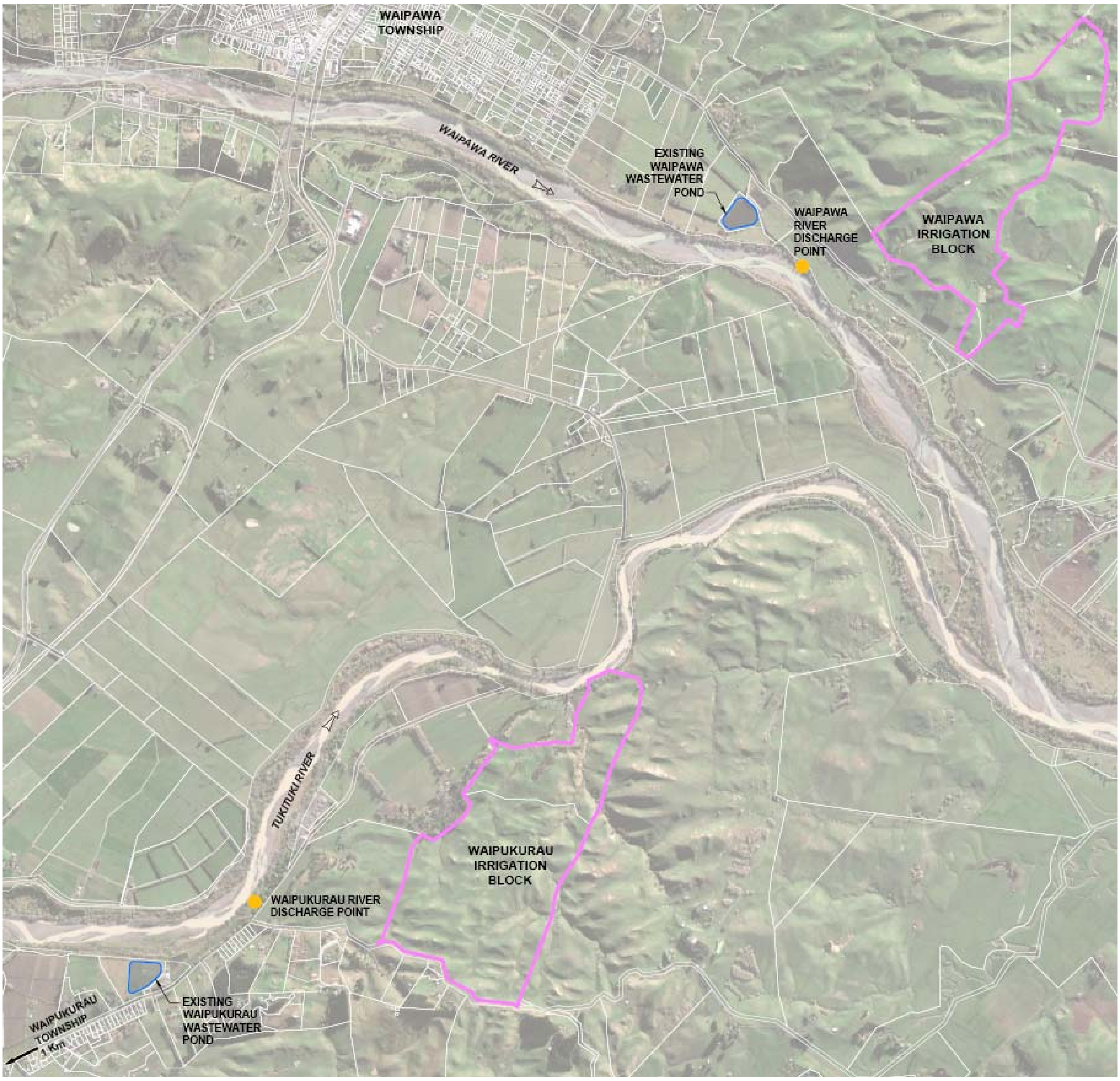
Currently the two wastewater treatment plants (WWTP's) discharge directly to the Waipawa and Tukituki Rivers. The existing effluent is partially treated in facultative aerated lagoons which allow for settlement of suspended solids and treatment through oxidation and biological degradation of the wastewater.

At times of low flow in the rivers the nutrients in the wastewater, specifically nitrogen and dissolved reactive phosphorus (DRP) result in the growth of periphyton (algae) and aquatic weeds.

Initially it was assumed that reductions in phosphorus concentrations in the effluent would be achieved using a conventional 'hard engineering' wastewater treatment solution, however, alternate solutions to reduce the effect of phosphorus are now proposed. This is done by reducing the mass load (through irrigation) and through targeting river discharge to occur only under certain river flow conditions. A portion of the effluent will be irrigated to two large blocks of land purchased by the Hawke's Bay Regional Council (HBRC). The two irrigation blocks are 123 and 79 hectares in size and are situated on hilly land close to the two treatment plants. Figure 1 shows the locations of the WWTP's, rivers and irrigation blocks.

This collaborative approach between the two Councils is providing a win/win outcome by reducing scheme costs for the CHBDC ratepayers and ensuring a better Resource Consent outcome for the HBRC by reducing the impact on the rivers

Figure 1: Plan View of WWTP's, Rivers and Irrigation Blocks



The following paper describes the development of a model, which determines the temporary storage volume required when the discharge capacity is exceeded and the timing and volumes of the discharges to land and river.

2 DATA ACQUISITION

Several different sources of data are required in order to develop a model for the scheme. These include wastewater outflows from the existing ponds, river flow and meteorological data; rainfall and evapotranspiration data.

2.1 RIVER FLOW DATA

Daily river flow data for Tukituki and Waipawa Rivers were obtained from 1989 to 2011 from CHBDC. The Tukituki River has been monitored at *"Tapairu Road"* approximately 3.5km downstream of the Waipukurau wastewater treatment plant. The Waipawa River has been monitored at *"RDS"* approximately 2.5km downstream of the Waipawa wastewater treatment plant. The median flows within the Waipawa River and Tukituki River are 8.6m^3/s and 9.3m^3/s.

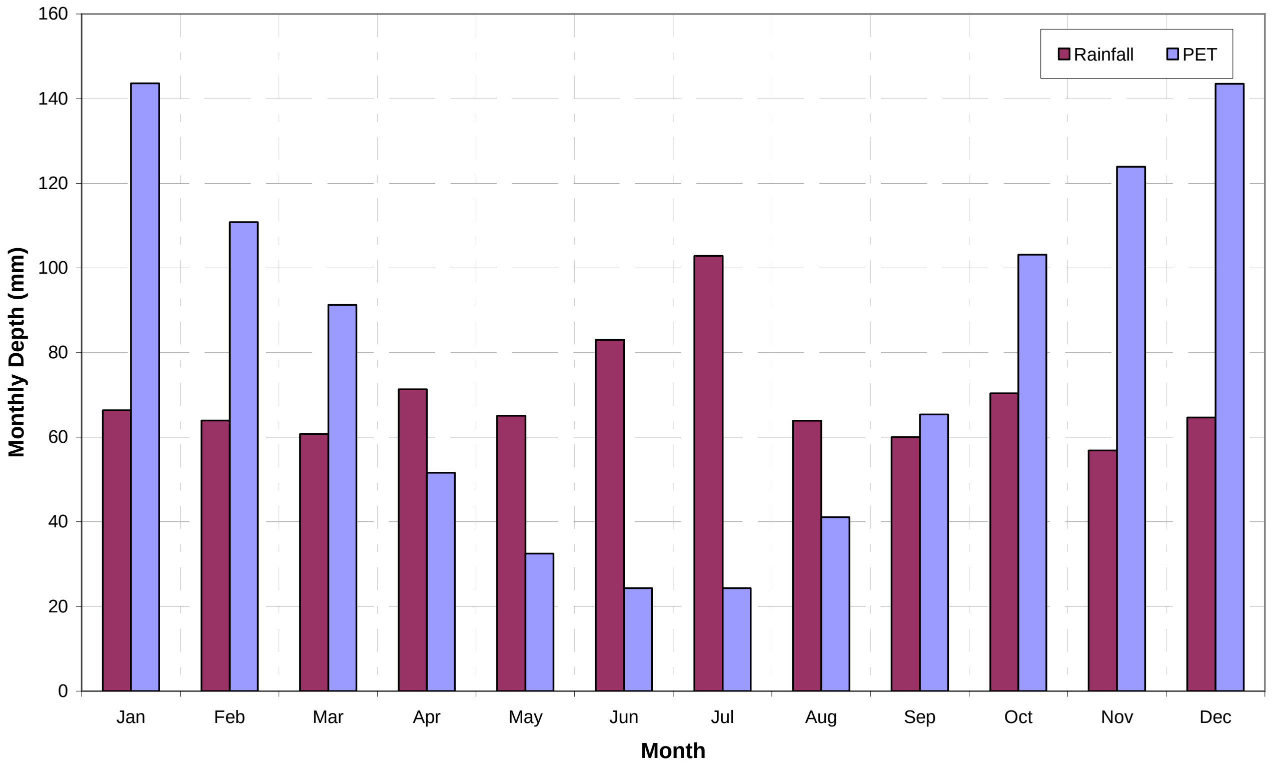
2.2 METEOROLOGICAL DATA

Rainfall and Penman PET (Potential Evapotranspiration) data have been collected for use in the water balance model. The aim of this data collection was to compile a data set which covered the period of river flow availability (1989 to 2011). All data has been collected from New Zealand's National Climate Database via NIWA's CLIFLO system.

A full rainfall data set over the period of river flows was available for the Mt. Vernon station. This climate station is between the two townships; approximately 2km north of Waipukurau and 4km south of Waipawa.

PET data were more limited than rainfall data and, in order to provide a data set equivalent to the river flow data set, the data from a number of stations have been utilised. By comparison of data overlaps between stations, conversion factors have been determined to allow data present at one station to be converted to that missing at another. Successive application of these conversion factors has allowed a complete data set to be built up which is considered to be representative of PET at the closest station at Waipawa Ews (Station Number 31620). Figure 2 shows the average monthly rainfall and PET over the model duration.

Figure 2: Average Monthly Rainfall and PET



Average annual PET from 1989 to 2010 is 990 mm. Average annual rainfall over this period is 830mm.

2.3 WASTEWATER POND OUTFLOW DATA

Daily treatment plant outflow data (referred to as wastewater flows) have been obtained from CHBDC for Waipukurau and Waipawa wastewater treatment plants from January 2008 until June 2011. Treatment pond outflow data were also obtained for a number of years prior to 2008, but after collating, due to the large and frequent data gaps, these data were considered to be of limited use and were not used.

The median wastewater flows over January 2008 until June 2011 for Waipawa and Waipukurau are 833m^3/day and 2038m^3/day respectively. The flows are shown in Figure 3 and Figure 4.

3 WATER BALANCE MODEL CONSTRUCTION

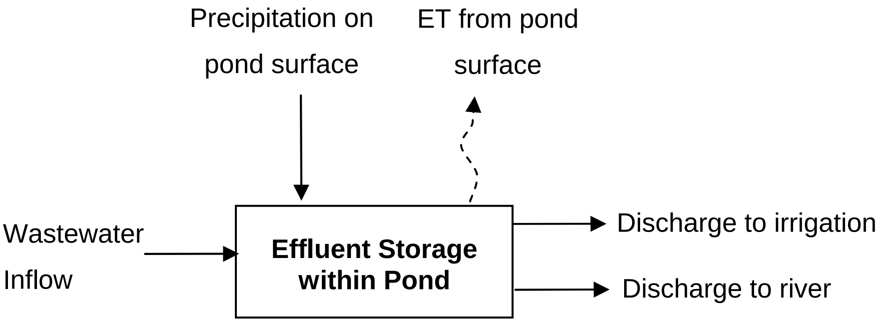
The overall water balance model incorporates daily wastewater volumes and river flows and calculates potential discharges to the river and to irrigation. Loadings of various wastewater quality components can also be determined using the model.

Discharge is dependent on the wastewater flow on the day, the build up of wastewater carried over from the preceding day and the potential to discharge to the river and irrigation. The formula below shows a basic form of the model:

Change in Storage = Wastewater inflow + Rainfall on the New Storage Pond Surface – ET from the New Storage Pond Surface – Irrigation Discharge – River Discharge

The figure below shows a graphical representation of the model. Discharge is prioritised so that any irrigation is utilised before river discharge is used.

Figure 2: Graphical Representation of Storage Model



The cumulative build up of undischarged wastewater, which rises and falls throughout the modelled period in response to variations in wastewater inflow and discharge outflow, represents the volume of wastewater that would need to be stored (or discharged by alternative means). The maximum build up volume within the modelled time series represents the maximum storage volume that would be required if all of the wastewater were to be stored.

To provide confidence in the selected storage values, the model is run over the longest period of data available. Initially this was constrained by the shortest data set; wastewater flows (2008-2011), however, data synthesisation has allowed it to be run over 22 years.

3.1 WASTEWATER INFLOW TO STORAGE PONDS

Whilst rainfall, PET, and river flows are available back to 1988, complete wastewater flow data are only available back to Jan 2008. For this reason synthetic wastewater flow data sets have been developed prior to 2008 for Waipawa and Waipukurau. When combined with the historic data this creates a full data set for the 1989 – 2010 period. The synthetic data has been generated through the use of a prediction model based on rainfall data as explained below.

The wastewater flow prediction model has been developed based on a correlation between rainfall and wastewater flows over the period Jan 2008 – Apr 2010 (the period of historic data available). Rainfall depth (x) was plotted against wastewater flow (y); the y intercept giving the base flow and the slope giving the flow dependence on rainfall in m^3/mm.

The wastewater flow prediction model was calibrated through comparison of observed and synthetic flows over the period of historic data. Initially the model used daily rainfall values to predict wastewater flows but this gave wastewater flows that responded too rapidly, resulting in highly variable flows. For this reason a rainfall weighting system based on antecedent rainfall was developed.

By testing different weightings and minimising the total difference in volumes between the actual and synthetic wastewater flows the following rainfall weighting was developed:

- 30% of the same day rainfall, 25% of the rainfall from 1 day before, 20% of the rainfall from 2 days before, 15% of the rainfall from 3 days before, 10% of the rainfall from 4 days before

The Waipukurau wastewater flows are matched with more accuracy (in terms of both peak flows and base flow) than the Waipawa wastewater flows. It is unclear why there should be a difference in response to rainfall between the two sites although different proportions of contribution from various inflow and infiltration (I & I) sources is expected to be important, along with increased stormwater overflows entering the WWTP.

Figure 3: Waipawa Wastewater Flow Synthesisation

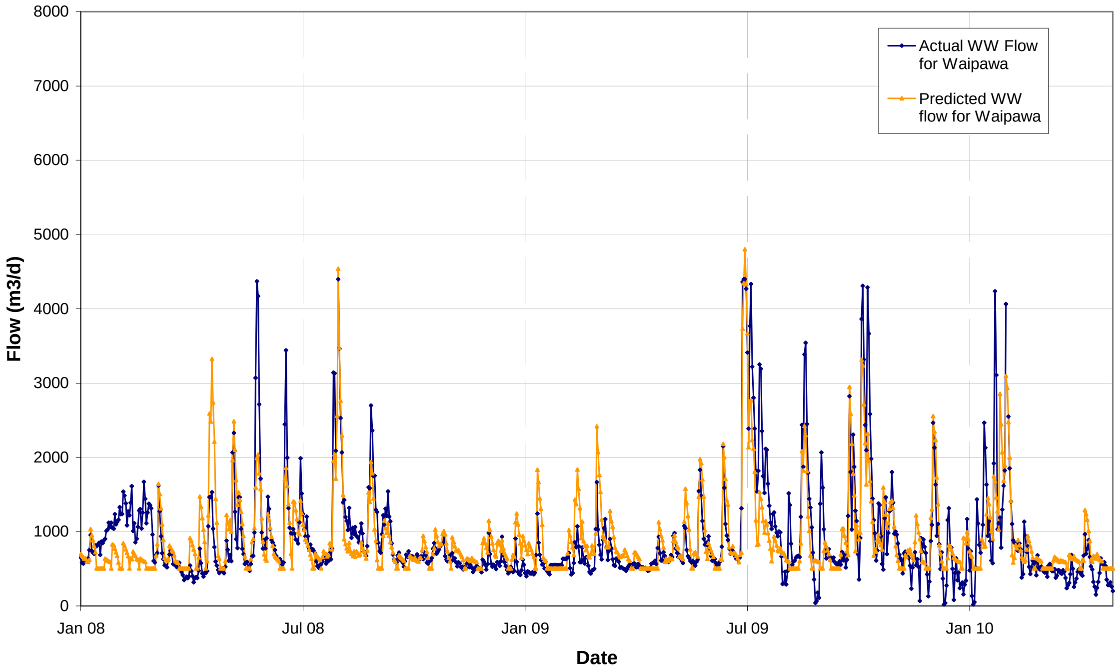
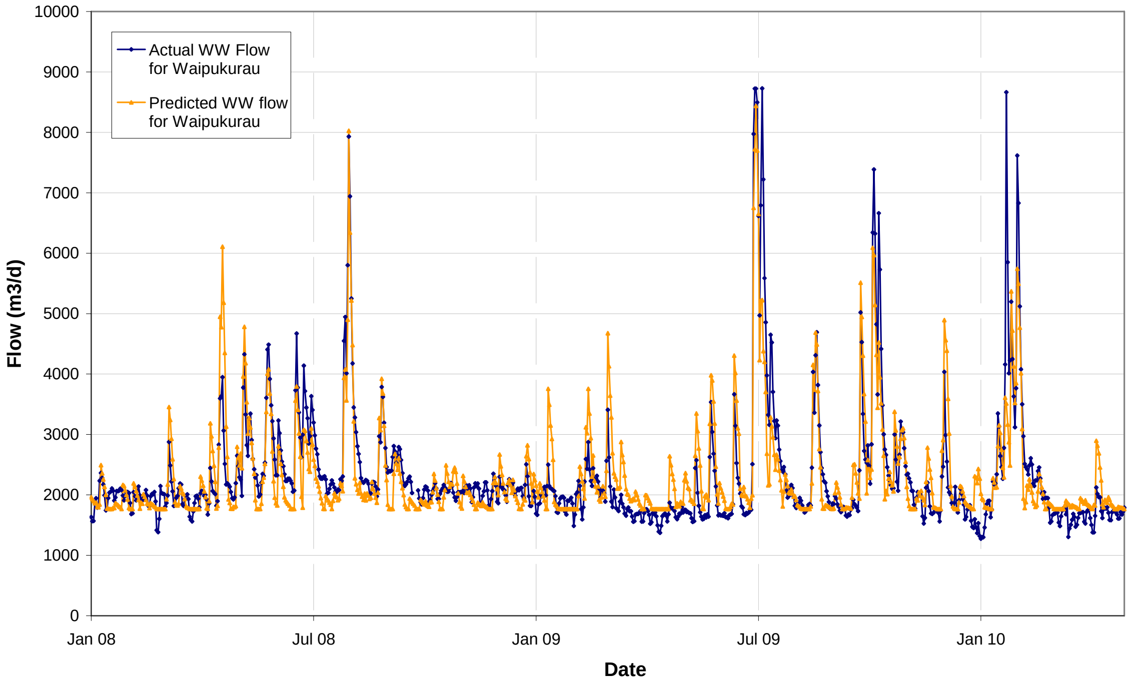


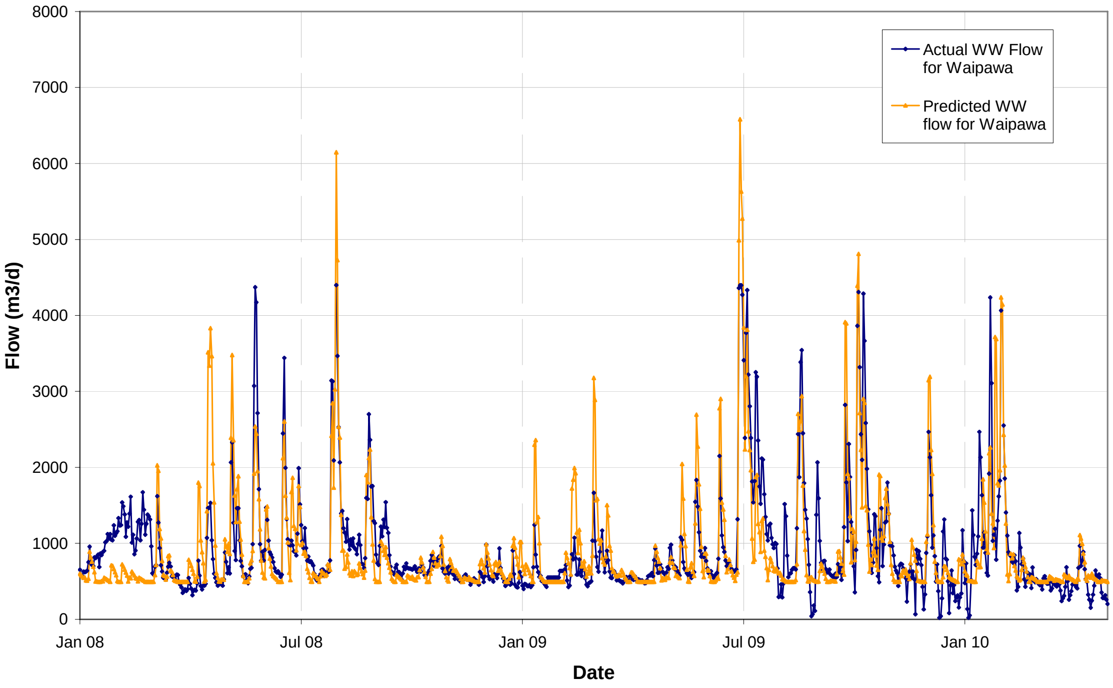
Figure 4: Waipukurau Wastewater Flow Synthesisation



The total wastewater volume under the synthetic plots is 779,000 m^3 and 1,973,000 m^3 for Waipawa and Waipukurau respectively. These volumes are very close to the actual volumes of wastewater of 773,000 m^3 and 1,965,000 m^3. The synthesised values represent very small over predictions in volumes of 0.7% and 0.4% respectively.

Although the total volumes match very well, the peak values are generally under-predicted for Waipawa. In order to more accurately predict these peaks, each one was closely analysed. In general these peaks are underestimated under high amounts of rainfall extending over periods of 2 to 3 days. In order to more accurately predict these flows an allowance for high rainfall events was incorporated (for more than 20mm of rainfall in one day, the same day and previous days rainfall weightings increased to 50%) and the overall volume scaled to match the actual flow over the calibration period. The modeled output using these criteria is shown in Figure 5.

Figure 5: Waipawa Wastewater Flow Synthesisation (High Rainfall Allowance)



Of note within the actual wastewater data is a small downward trend in base flow. This downward trend may be due to the I&I reduction programme presently being undertaken by CHBDC. This can be seen on Figure 3 and 4 with apparent reductions in late 2008/early 2009 of about 180m^3/d and 120m^3/d for Waipawa and Waipukurau respectively. Because the wastewater flow calibration being is over the complete period of historic data, it will tend to overestimate more recent wastewater flows. This will make the model conservative in selecting design volumes because of a calibration to higher historic wastewater flows and an over-prediction in wastewater volume, provided the long-term reduction effects of the I&I programme remain effective. This is probably unlikely to be the case below a certain level as I&I is likely to start to increase again over time as pipes crack and move with time and illegal house roof connections occur.

3.2 PRECIPITATION AND EVAPOTRANSPIRATION ON POND SURFACE

Modelling of the buffer storage required pond surface areas to be selected to incorporate rainfall and ET on the surface of the storage ponds. Pond areas were selected based on a pond depth of approximately 2.5-3.0m and the final selected pond volume. ET for open water is subtracted from rainfall on a daily basis and this value is applied over each area to determine the net influx/outflux. On an average yearly basis there is 830mm of rainfall and 1030mm of ET from the pond surface, this gives an average annual outflux of 200mm.

3.3 IRRIGATION DISCHARGE

The irrigation discharge is based on a relatively simple soil moisture accounting model contained within the larger water balance model. The irrigation model is run on a daily basis with a soil moisture store that can be filled or depleted depending on a number of inputs and outputs. This is termed the “Deficit Irrigation Regime”. Inputs and outputs are summarised below:

- Inputs = Rainfall, irrigation
- Outputs = Actual Evapotranspiration (AET), runoff/percolation

On each day, rainfall is added to the store and AET is removed. If the resulting soil moisture content exceeds the field capacity (FC) then the remainder is assumed to runoff or go to deep percolation. If removal of the PET would result in the soil moisture content falling below the wilting point (WP) then the soil moisture content is fixed at the WP and the PET is reduced accordingly ie the reduced PET is the AET. The soil properties used in the model have been taken from reports prepared by others.

A crop factor has been used in the calculation of PET. This factor is used to multiply the Penman PET to determine a PET based on the crop cover on site. Grass cover is assumed in the short term, until full establishment of the Eucalyptus and Pine Forest takes place, where a larger crop factor has been adopted.

The potential for irrigation is determined following the calculation of soil moisture after application of rainfall and PET. A safety buffer of 5 mm below FC has been set for irrigation, which means that the amount of irrigation that may occur must not result in soil moisture being within 5 mm of field capacity.

A second restriction to irrigation has also been employed based on weather forecasting. Irrigation is restricted if rainfall is forecast to occur on the next day. This restriction will help to minimise runoff and deep percolation occurring during heavy rainfall events.

A final restriction is applied based on the hydraulic capacity of the soil which has been determined to be 8.45 mm/day. A maximum irrigation rate of 6.0 mm/day has been adopted for each site.

After incorporation of all restrictions the irrigation quantity is determined and added to the soil moisture content. The resultant soil moisture content is then carried on to the beginning of the next day.

3.3.1 EROSION RISK

Field work completed by PDP from 25th to 28th July has determined categories of irrigable land on each site based particularly on consideration of the slope stability of the land. There are four irrigation categories; full irrigation, limited irrigation, potential future irrigation and no irrigation. The areas are classified in Table 1.

Table 1: Irrigable Areas for Waipukurau and Waipawa

Irrigation Category		**Category Area (ha)**		
		Waipukurau	**Waipawa**	**Reasoning**
Full Irrigation	Deficit Irrigation *(all of year)*	62.6	34.2	No slope instability present or rare remnant/revegetated slope instability features.
Limited Irrigation	Deficit Irrigation (nominally *1st Oct - 31st Mar*). Potential for full irrigation once tree canopy established	14.3	8.5	•Few-some slope instability features but remnant/revegetated - typically on steep slopes. •Ephemeral Water Course and wet slope area (expected to be dry over summer)

Potential Future Irrigation	Potential for Limited Deficit Irrigation (nominally 1st Oct - 31st Mar) but only once tree canopy is established	5.5	9.8	•Many slope instability features (remnant/revegetated) typically on very steep slopes. •Extremely steep slopes with no instability/erosion features.
No Irrigation	No irrigation at any time	40.9	26.8	•Active slope instability •Extremely steep slopes with remnant revegetated landslide features •Perennial Water Course/pond •Area is within 20m of permanent water course/pond or within 20m from property boundary. •Bedrock near/at ground surface

3.4 RIVER DISCHARGE

River discharge restrictions are based on the advice of ecological experts from HBRC and the rules contained in the operative Hawke's Bay Regional Resource Management Plan (RRMP) and are aimed at minimising the ecological effects of the discharge.

The water balance has been set up primarily on the basis that any treated wastewater discharge into the receiving rivers of the Tukituki and Waipawa rivers does not increase the Dissolved Reactive Phosphorus (DRP) in either river to more than 0.015mg/l (in accordance with the RRMP) when flows are below 3 x median flow. During the course of the project it was discovered that background concentrations upstream of the WWTP's were at, or close to, the 0.015mg/l limit at present. As a result, the model essentially only permits a discharge to the rivers when river flows exceed 3 x median flow.

At 3 x median flow the bed of the river is mobilised. This flushes any attached algae, resetting the river to a 'clean' state. Therefore, at river flows greater than 3 x median flow an unlimited discharge to the river may occur as long as there are no toxic effects.

The model is setup so discharge occurs at a rate of 500L/s from a WWTP only when both the respective river flow and the combined flows exceed 3 x median.

A summary of the flow conditions for the two rivers are shown below in Table 2. These statistics were calculated over the period of Jan 1989 - March 2011.

Table 2: Flow Statistics

	25th percentile, (m3/s)	Median, (m3/s)	3x Median flow, (m3/s)
Tukituki	5.4	9.3	27.8
Waipawa	5.1	8.6	25.8
Combined flow	10.6	18.0	54.1

4 MODEL RESULTS

4.1 STORAGE VOLUMES

The final model incorporating both irrigation and river discharge has peak storage volumes of 80,000m^3 (Waipawa) and 210,000m^3 (Waipukurau) as shown in Figure 6 and Figure 7 respectively.

Significant peak storage events occur primarily in July and August resulting from low discharge to both land and river. River discharge is typically greatly reduced prior to these large peak storage values due to a small number of days exceeding 3 x median river flows and restricted irrigation due to higher rainfall and lower ET.

Figure 6: Waipawa Storage Requirements

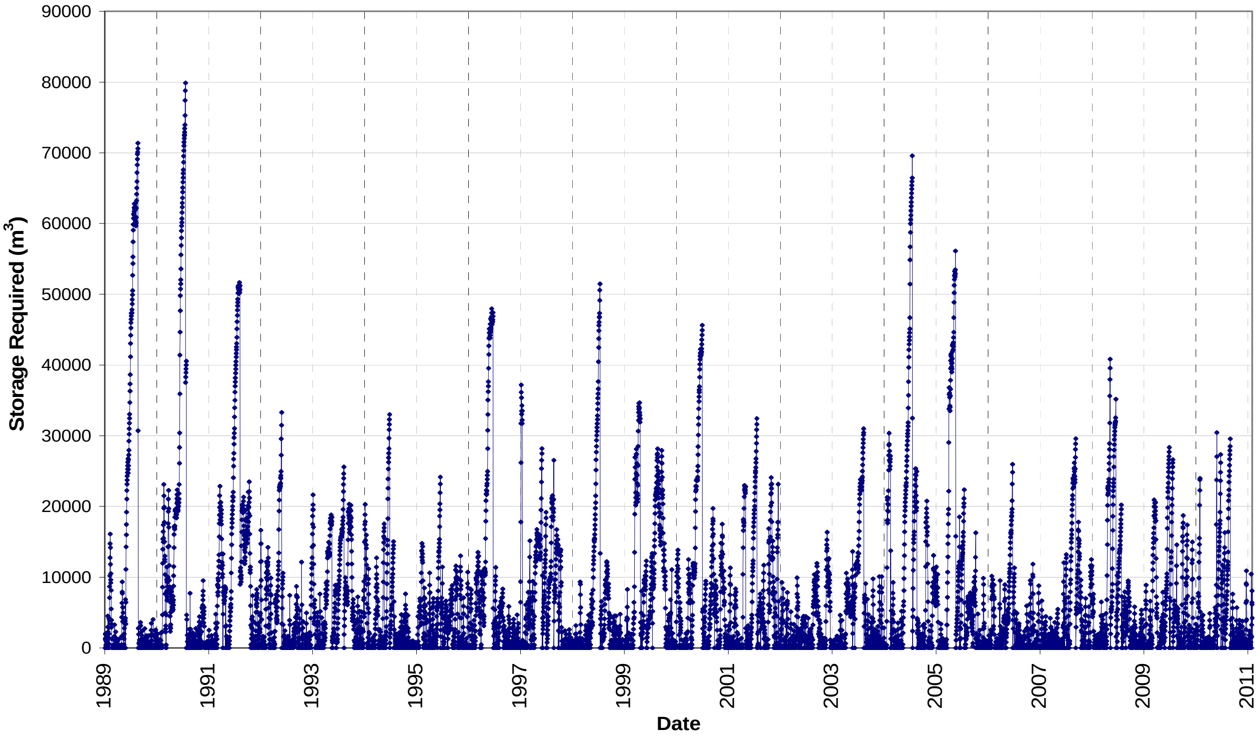
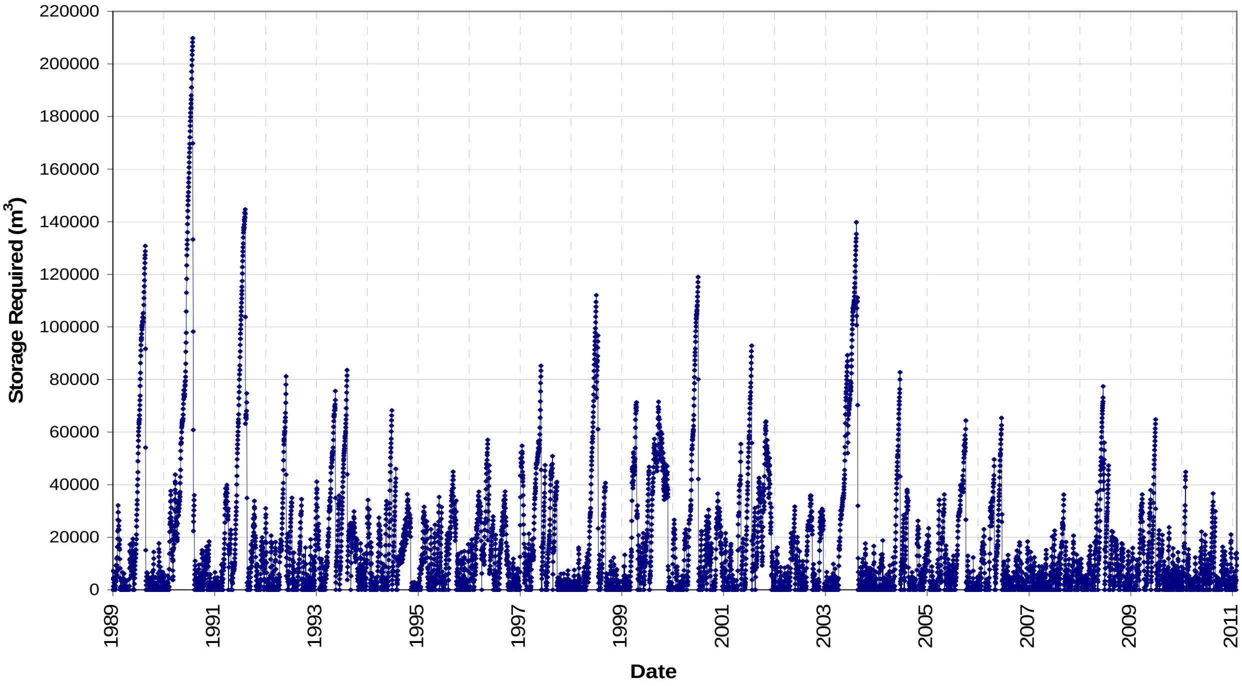


Figure 7: Waipukurau Storage Requirements



Although provision of the peak storage volumes would cater for the entire modelling period, the requirement to store large volumes only occurs occasionally and for relatively short periods of time. Given the expense of providing this volume of storage and the fact that it would only be partially used for the majority of the time, alternatives, using lower storage volumes are being considered.

Construction of smaller storage volumes will require river discharges to occur outside of the discharge constraints previously discussed (these discharges are referred to as “storage exceedance events”) but allows a smaller capital cost for the construction of the storage ponds. Storage exceedance events are assumed to occur over a period of 24 hours at a rate of 500 l/s from each site (1000 l/s combined).

The use of storage exceedance events has implications for ecological effects which need to be considered. These events represent discharges which are outside the ecological effect-based limits which have been set for discharges (e.g. discharge only when river flows are greater than 3 x median flow). However, the nature of these events, which are of short duration and infrequent rather than a constant discharge, means that the exceedance of the limits is unlikely to represent a significant ecological effect.

To assess the ecological effects, NIWA has been employed to review a number of scenarios, each of which uses a different storage volume. These scenarios result in a particular pattern of storage exceedance events throughout the model period, with the number of events increasing as the selected storage value decreases.

At this stage a moderate storage scenario has been selected as suitable from the point of view of ecological effects based on preliminary results from NIWA. This scenario is defined as a constructed storage volume of 60,000 m^3 at Waipawa and 120,000 m^3 at Waipukurau.

4.2 DISCHARGE VOLUMES AND TIMING

The average monthly discharge volumes were determined for the final 22 year model run. The two wastewater treatment plants have a similar pattern of discharge to the river and as irrigation as shown in Figure 8 and Figure 9. The discharge patterns are similar for both sites along with the proportion discharged as irrigation (52%).

Irrigation volumes peak in January, remain relatively high until March, before dropping away during April-May. During June and July irrigation volumes are insignificant (being less than 3% of the total discharge volume), but they then steadily rise from the end of July until the peak discharge volume in January.

River discharges behave in an opposite manner in response to seasonal changes in rainfall and, hence, river flows. Discharge volumes to the river are at their lowest from January to March (when river flows are also lower). They then begin to rise steadily to a peak volume in July, which in general corresponds to significant emptying of the temporary storage ponds (because of elevated river flows).

Figure 8: Waipawa Discharges

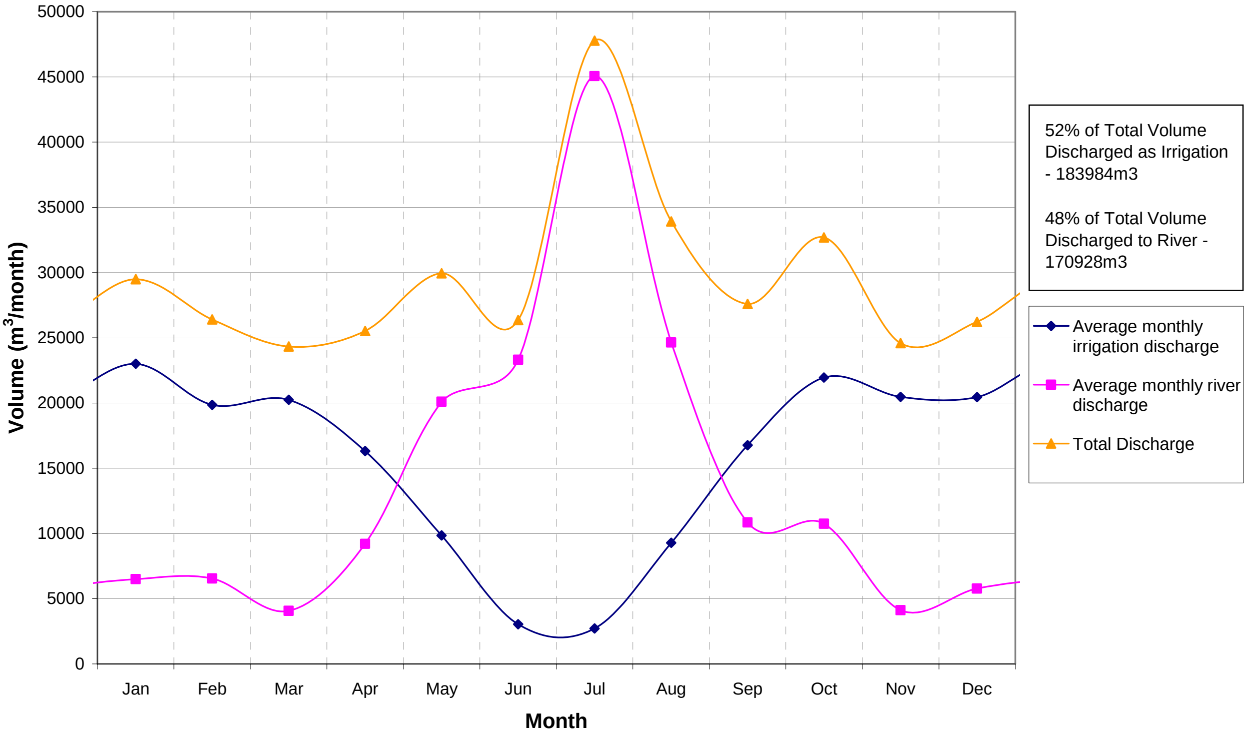
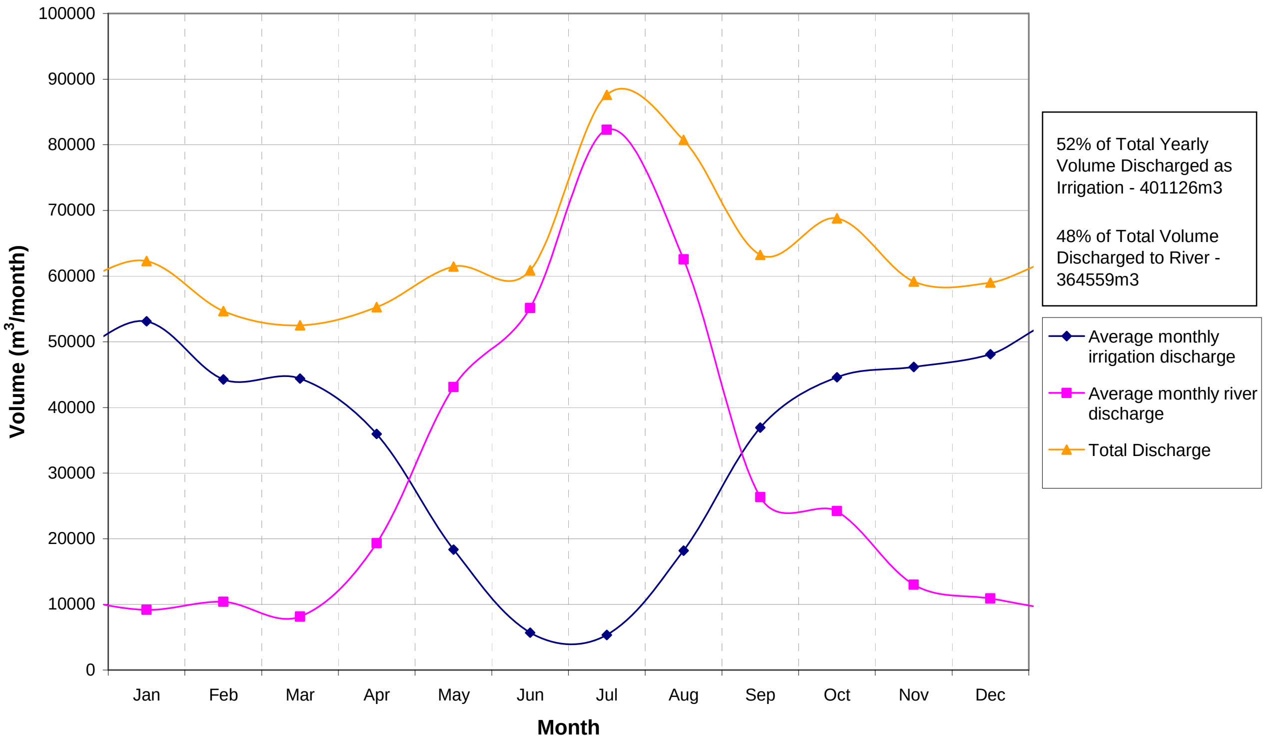


Figure 9: Waipukurau Discharges



5 CONCLUSIONS

The developed model and subsequent analysis has provided insight into feasibility and design of the proposed dual discharge scheme.

The model is constrained by different factors for river discharge and discharge to irrigation. River discharge is constrained by discharge limits controlled by the respective flow in each river, whilst irrigation is constrained by soil moisture and the area of land available to irrigate at the Waipawa and Waipukurau forestry blocks.

Peak storage volumes have been determined based on 22 years of data (some of which is synthesised). These peak volumes occur in 1990 with respective volumes of 80,000m^3 and 210,000m^3 for Waipawa and Waipukurau. Significant peak storage events occur primarily in July and August resulting from low discharge to both land and river.

Adoption of the peak storage volumes for construction would ensure that ecological requirements of river discharge were met. Assessment of the ecological effects of selecting smaller storage volumes is currently being undertaken by NIWA. This is primarily focused on the potential for enhanced periphyton growth in the river due to high phosphorus concentrations. At the time of writing this report a moderate storage scenario, representing storage volumes of 60,000 m^3 at Waipawa and 120,000 m^3 at Waipukurau, has been assessed to be suitable.

The model shows that the proposed scheme will remove significant proportions of treated wastewater from the rivers, with 52% being removed and discharged as irrigation for both sites. The timing of irrigation, occurs primarily between November and March, and restriction of discharge to river (except under 3 x median flow) significantly reduces the phosphorus loading to the rivers overall and practically eliminates it at ecologically sensitive low flows.