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Interactive Comment

Interactive comment on "Investigation of groundwater-surface water interaction using hydrochemical sampling with high temporal resolution, Mangatarere catchment, New Zealand" *by* M. R. Guggenmos et al.

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Overall author's response: Both referees have referred to major (known) limitations surrounding the quantification of surface water and groundwater interaction using mass balance calculations. These limitations include the lack of consideration for evapotranspiration and bank storage, and the high uncertainty and error surrounding the calculation of discharge from foreign linear rating curves. Although attempts were made to address these issues, we do not believe we have been able to adequately achieve this

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Interactive Discussion

Discussion Paper

given the paucity of the data used to formulate the mass balance equations. Considerations for evapotranspiration were easily included in the mass balance calculations, however without obtaining additional field observations for surface water discharge it is not possible for us to reduce the uncertainty surrounding the calculation of discharge datasets from stream stage. As a result we have decided to remove the mass balance calculations from this research. Despite the removal of Section 4.5, this research would benefit from quantification of groundwater and surface water investigation using an accurate mass balance approach and it is recommended that

Additional responses in regards to each individual referee comment are provided below:

Anonymous Referee Number 2 Comments received 12th January. 8, C5691–C5695, 2012

1. Evapotranspiration (ET): ET is often a significant fraction of stream water balances. The authors claim that it is unimportant over 10 km of stream reach, but do not provide evidence to support this claim. This seems unlikely, especially if there is a riparian corridor (also no mentioned). Also, given significant discussion by the authors of how water from smaller precipitation events does not contribute to groundwater recharge but is instead stored in soils, it seems likely that bank storage could also be an important mechanism of stream discharge loss. These mechanisms need to be considered, or a stronger argument needs to be made that they are unimportant. This assumption affects both water and solute mass balances, and thus has implications for the calculations B1 and B2, as well as the data presented in Figures 7 and 8.

Response: There is an agreement that water losses by evapotranspiration can be a significant fraction of surface and groundwater water balances. However, due to the low average annual potential evapotranspiration rate (approximately 780 mm per year) for the area evapotranspiration was not considered an important process for this water balance. This was due to the low annual temperatures, length between gauging stations and the small riparian corridor surrounding the Mangatarere stream. Regardless, a rate of water loss through evapotranspiration was added to each water balance. Results found that losses through evapotranspiration were insignificant and did not influence the current findings or outcomes of these simple mass balance equations. However, despite this comment being addressed, a large level of uncertainty still surrounds these mass balance calculations leading to their exclusion from the manuscript.

2. In this paper, groundwater/ surface water (gw/sw) interactions are inferred from differences in stage, chemistry, and discharge between the upstream and downstream gages. It is difficult to make a strong argument given the paucity of the data. Multiple studies exist that show the dangers of relying on total discharge to infer these processes (see K. Bencala et al. 2011 and R. Payn et al. 2009 both in Water Resources Research). More rigorous methods for considering gw/sw interactions, such as stream tracer additions or installation of shallow subsurface wells in the streambed along the 10 km study reach could provide useful data to support the author's claims. As is, the data is equivocal and the interpretation is generally speculative. It is very likely that there is both upwelling and downwelling within the study reach. It's quite possible that the two active faults that cross the stream have an effect on both subsurface flow and chemistry (and thus the mass balances). Consideration of these faults and their effects could have implications for the results and interpretation.

Response: There is a general disagreement with this referee comment as this paper has employed multiple methods (e.g. water chemistry, temperature, water stage) to demonstrated the extent of groundwater and surface interaction in the Mangatarere stream. Yes, there are a number of limitations that surround each method and one should not speculate using one set of data alone. For this reason multiple methods have been employed and the resulting data used to strengthen the argument from the previous method. Further, all major findings are supported with evidence from the scientific literature. Limitations and alternative outcomes and/or processes that may be responsible for certain data trends are also explored and discredited where possible.

This referee also points to the need to use alternative methods such as stream tracers or shallow subsurface wells. Although it is acknowledged that these methods may be useful for this study, it is not possible to obtain new supplementary data. In addition, the preference of methods to investigate groundwater and surface water interactions is subjective and due to the circumstance surrounding this Masters research (e.g. monetary and temporal restrictions, student knowledge) the methods employed in this paper were found to be the most practical at the time.

It is acknowledged that there is both upwelling and down welling within the study reach, hence classification of the upstream and downstream reaches as different zones of interaction (upstream losing, downstream gaining). The scientific literature (e.g Keery et al., 2006) suggests groundwater and surface water interaction may occur and/or change over finer spatial scales (km, several hundred metres), however investigation of finer spatial scales were beyond the scope of this project which focused on interaction along the entire Mangatarere stream reach (ca. 10-15 km).

It is thought the Carterton fault may mark the transition from the losing to gaining stream system. However, this is currently not discussed in much detail within the text. The Carterton Fault line has resulted in low permeability sediments being forced close to the surface. This may modify groundwater flow paths, forcing groundwater toward the ground surface where they can contribute a greater proportion of baseflow to the Mangatatere stream. This will be mentioned in further detail within the revised manuscript.

3. Groundwater/surface water interactions inferred from groundwater temperature. The apparent temperature increase does correspond to the two largest periods of precipitation, but I'm surprised that there is not a lag between the maximum daily air and groundwater temperatures. Is the difference in water levels so small that the lack of lag is reasonable? Such a fast response might be expected from water short-circuiting the porous media and flowing along the well casing. It would be useful to see this period of Figure 5 in a larger size to better analyze this. Also, the major period of ground-

water warming corresponds closely to periods where the groundwater stage appears erroneous. Is this just coincidence?

Response: In general, changes in groundwater temperature do not follow daily maximum air temperature and instead are influenced by the mean average air temperature (Brunke and Gonser, 1997). Exceptions can occur when the water table is close to the ground surface. During JD026-028 water temperature at the upstream groundwater station displayed a diurnal temperature pattern. This diurnal pattern occurred approximately three days after the maximum rainfall event on JD022-023 and has been used to infer the recharge of stream flow to the local aquifer. The three day lag period is currently not emphasised within the text, but suggests the transfer of this diurnal pattern was not instantaneous and the front of surface water recharge to the aquifer likely occurred after several days. Alternatively, the presence of this diurnal groundwater temperature pattern may have been due to the water table rising to the ground surface and the conductive transfer of heat through the soil zone to the water table. However, this is unlikely to have occurred during this period as the upstream groundwater table did not show a diurnal response during other periods of the study when the distance between the water table and the ground was similar. Further, conductive heating would have been reduced by the presence of pastoral grass on the ground surface and the various sand and silt layers which display low thermal conductance values (Baver, 1940; Campbell, 1985). An additional explanation would suggest this diurnal groundwater temperature may be due to purging of the bore during the hydrochemical sampling programme. However, the upstream bore was not purged for extended periods of time, as it would run dry, and therefore it is unlikely heat was transferred through the open casing.

There is a general disagreement with the referees comment that groundwater stage appears erroneous during the period of groundwater warming. The overall change in water stage during this period reflects the significant recharge to the system, whilst the small fluctuations in stage are due to purging of the well for hydrochemical sampling. It

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is therefore not deemed a coincidence that this may have implications for the temperature data. In addition, all pressure transducers and temperature probes were calibrated before and after the study period.

4. Catchment Hydrology Results: I'm confused by the y-axis in Figure 3. Where is the datum for water stage? It appears that the upstream groundwater has a head that is approx. 2.5 m above the surface water. This implies an upward gradient, and would seem to preclude infiltration/recharge from the stream to the subsurface. I'm also surprised that there is almost no stage difference between the upstream and downstream surface water gage. I'm guessing that these three lines have different datum. Also, in the text at 10237-11, ": : :downstream stage generally 10 cm higher". Since water flows from high head to low, this suggests water is flowing upstream. Please clarify.

Response: Surface water and groundwater stage are presented on different height datum's, with groundwater stage reported as metres below ground level and surface water as metres above the stream bed. This has now been clarified in the text and Figure 3. As groundwater and surface water stage are not adjusted to a common datum, an analysis of water gradients in order to investigate and/or confirm groundwater and surface water interaction has not been undertaken. Instead changes in water level and the magnitude of change between gauging stations are emphasised.

In regards to the difference in stage between upstream and downstream surface water gauging stations, a 10 cm increase is considered a significant stage difference as the downstream surface water gauging station has a larger cross sectional area and hence discharge in comparison to the upstream site. This should clarify the referees comment in regards to Line 10273-11 as surface water stage is reported as depth above the stream bed not as a relatively datum. Specific Comments

Specific Comment: Abstract and Introduction: I agree that short timescales are important for considering gw/sw interactions, but I don't think it's fair to say that short (< weekly) timescales have not been studied. There are many examples of rigorous stud-

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ies, either through modeling or tracer-based methods that focus on high spatial and temporal components.

Response: The referee does not support the suggestion that short timescales are often neglected in investigations surrounding groundwater and surface water interaction. However, it was never the author's intention to make this claim. Instead the introduction outlines that the majority of investigations are conducted at larger temporal scales due to operational and monetary constraints. The introduction goes on to mention that research within the literature has found that groundwater and surface water interaction occurs at smaller timescales and hence there is a need to investigate this further. To strengthen our argument we will seek to provide more examples of high resolution works that have investigated groundwater and surface water interaction over short time scales (e.g. Silliman et al., 1993), in particular focusing on how such investigations have increased our understanding and therefore warrant additional research.

Specific Comment: Field Site: Given the high winter temperatures (up to 24C) and the dry fohn winds, it seems like evapotranspiration (ET) could result in a significant loss of water from this stream. The authors need to at least mention ET, and indicate if it might be a substantial fraction of the stream water budget.

Response: Refer to major comment above in regards to evapotranspiration. As this aspect has been removed from the article this comment is no longer relevant.

Specific Comment: Field Methods: Were the absolute pressure transducers corrected for barometric pressure fluctuations? This is not mentioned.:

Response: Each absolute pressure transducer was corrected for barometric pressure. This has been clarified in the field methods section: 'Each absolute pressure transducer was corrected for barometric pressure using a mini BaroTroll installed at the upstream groundwater gauging station.

Specific Comment: 10237-10-15: For the comparison of the upstream and downstream flows, it would be better to quantify discharge instead of inferring discharge from stage. Larger catchment area and greater distance downstream are not always good reasons to expect higher discharge at the downstream gage.

Response: The referee suggests the use of discharge, as oppose to water stage, for the comparison of upstream and downstream flow. It is agreed that accurate discharge measurements would be better suited, however as identified in the article no discharge data was collected from the surface water stations and a number of major limitations and assumptions surround the determination of discharge through indirect methods. Therefore, in order to reduce the introduction of error into the initial interpretations of groundwater and surface water interaction water stage data was used with discharge inferred by water depth (stage) and the cross sectional area of the respective surface water gauging stations. The assumption was made that discharge is higher at the downstream surface water gauging station due to the larger cross sectional river channel and the higher stream stage. As stream stage increases the volume of discharge also increases. This will be clarified further in the text.

Specific Comment: 10238-0-2: Higher EC does not necessarily signal stream recharge, and could also indicate evaporation between the upstream and downstream gages, or small high concentration inputs from the fault zone.

Response: Elevated EC alone does not indicate the provision of baseflow from groundwater sources. However, as suggested in the manuscript elevated concentrations of sodium, chloride and nitrate, parameters known to accumulate in groundwater due to the passage of precipitation through the soil zone, suggest a groundwater chemical signature is being transferred to the surface water body. Although the nutrient nitrate may be flushed into the stream from agriculture runoff and tributary creeks, this is only likely to occur during high rainfall events when these creeks are flowing. The presence of nitrate at the downstream surface water gauging station during baseflow conditions suggests nitrate is being provided as a constant source to the stream which a groundwater baseflow component would certainly do. In addition, it is unlikely evaporation along the 10 km reach would contribute to the 20-30 uS/cm and 15 mg/L TDS increase experienced between the upstream to downstream surface water gauging stations due to the low evaporation rate for the area (approximately 780 mm/year). This will be clarified in the text with a stronger argument provided.

It is a possibility that the Carterton fault line may provide water with an elevated concentration of TSD. The conceptual hydrogeological model suggests the uplift of impermeable sediments has forced groundwaters up towards the surface where they then begin to provide a significant component of baseflow to the downstream surface water gauging station. The role of the fault line in providing groundwaters or water with an elevated concentration of TDS will be clarified in the text.

Specific Comment: 10238-4-5: How is runoff generated from groundwater?

Response: This sentence was incorrect and should read: Following dilution events, downstream surface water EC tends to return to base conditions faster than upstream, suggesting that the majority of stream flow following the initial peak flow is provided by a groundwater baseflow component.

Specific Comment: 10244: It seems like several of the downstream surface water attributes including higher EC, elevated TDS, nitrate, ammonium, and P could have originated from agricultural runoff. How do you know that their presence is related to gw/sw interactions? The authors mention (line23) that these could come from tributary streams, and I think this sounds more likely.

Response: It is agreed that downstream surface water attributes such as higher EC, elevated TDS, nitrate, ammonium and phosphorous may have originated as agricultural runoff. However, it is unlikely agricultural runoff was provided to the downstream surface water site during baseflow conditions as the majority of runoff would only be mobilised during rainfall and runoff events. Tributary creeks only provide water and runoff during high rainfall events. This being said, there is still a level of uncertainty as to whether these attributes are provided by groundwater sources, hence this assumption is supported with groundwater and surface water temperature data and examples from the scientific literature. Work by Burden (1982), Taylor et al. (1989) and Rozemeijer and Broers (2007) have all found these nutrients accumulate in rainfall-recharged groundwaters and are transferred to surface water sites through the provision of baseflow.

Specific Comment: 10246: Unless the entire stream discharge is moving through a flume or weir, linear interpolation between each rating point would likely produce a more realistic and accurate rating curve than relying on a single equation.

Response: The determination of discharge values from stream stage has been removed from this manuscript due to the high level of uncertainty surrounding the dataset and resulting discharge values and mass balance calculations. See above.

Specific Comment: Figure 7 & 8: Error bars on the discharge calculations would be useful: : : can you accurately quantify groundwater inputs via this method? ie. by subtracting one large number (downstream discharge) from another large number (upstream discharge) to get a small number (recharge) likely results in large errors.

Response: The error associated with the determination of discharge is likely in excess of 15-25%. When this error is transferred through to the mass balance calculations it makes it extremely difficult to accurately quantify groundwater inputs to baseflow as this volume is likely exceeded by error. As a result, the mass balance calculations have been removed from this manuscript.

Specific Comment: 10247: Ignoring evapotranspiration could lead to significant errors in the % mass balance calculation. Tracer dilution in the reach of expected groundwater recharge would provide another, more accurate method of quantifying inflows to the stream.

Response: The referee is directed to major comment above in regards to evapotranspiration. This comment no longer applies due to the removal of the mass balance calculations.

Specific Comment: 10253: In the mass balance at B2, there should be a negative sign before the upstream component (ie. US + groundwater = DS).

Response: No longer applicable.

Specific Comment: 10254-1: I have a hard time believing that the rating from the Gorge can effectively estimate discharge at the upstream gage! I think you need to provide channel cross sections, slopes, and roughness values to support your claim that this rating can be transferred from one location to another. Better yet, develop a rating curve for the upstream gage.

Response: It is not possible for the collection of additional data to support the application of the Mangatarere at Gorge rating curve to the upstream surface water gauging station. Therefore, the uncertainty surrounding this application cannot be reduced and as mentioned previously the mass balance equations have been removed from the manuscript.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 8, 10225, 2011.