Response to the comments of reviewer #1:

We thank the reviewer for the time examining the manuscript and the valuable comments that have provided insights on how to improve it. We have carefully addressed the comments in the following response and provided some further analysis to clarify the reviewer's major concerns. The comments of the reviewer are in black and our response are in blue.

General comments:

In this study, the authors systematically investigated the responses of tidal hydrodynamics in terms of water retention time (including the water age and bulk flushing time), salinity and stratification to the drying climate trend (decrease in river flow inputs) and the opening of a large artificial channel. The obtained results are of particular importance for developing the corresponding sustainable water resources management strategies in such a large shallow lagoon system. However, there are still some major concerns that should be carefully addressed in order to improve the quality of this manuscript.

Major concerns:

1. It should be noted that the Peel-Harvey lagoon (or estuary) is a typical tide-dominated system although it experiences a micro-tidal regime with tidal range generally less than 1 m. This is mainly due to the large estuarine surface area (133 km^2) and hence the large estuarine volume (187.5 GL). This indicates that the tidal hydrodynamics is generally featured by both the seasonal change and the spring-neap change. For the time being, the main results only focus on the seasonal change in tidal hydrodynamics, while the spring-neap change did not investigate at all.

Response: We agree that the spring-neap tide change is an important driver of the changes in hydrology over the short-term scale. This study focused on examining the long-term changes in hydrology, considering the seasonal and inter-annual features of the estuary in response to climate change and catchment inputs, and therefore the changes in the system between the spring and neap times of the tidal cycle were not reported. However, our model does resolve these variability at this scale and have therefore explored the tidal cycle impacts on the hydrology in more detail in the response to the following comment related to the spring-neap changes in water retention time.

2. For the spring-neap change in the water retention time, it would be worth exploring the impacts of residual water currents on spatial-temporal variation in the water age and bulk flushing time. For instance, the difference of the residual water currents during the spring tide period before and after the opening of the artificial channel can be used to show the underlying mechanism of the change in water retention time. Similar results can be obtained for the neap tide period.

Response: Noting that the system experiences a micro-tidal regime, we agree the spring-neap tide is a key driver of the short-term hydrological changes in the estuary, and therefore present a further investigation of this. We first analyzed the tide constituents of the Fremantle tide elevation record with the U-Tide utilities (Codiga, 2011). The results, as shown below in Table 1, identified the lunar diurnal constituents (K1, O1) contribute most of the tide potential energy, followed by the solar diurnal constituent (P1), principal lunar semidiurnal constituent (M2), and principal solar semi-diurnal constituent (S2).

Table 1. Principal tidal constituents for Fremantle tide record

Constituents	Potential Energy (%)	Amplitude (m)	Greenwich phase lag (degrees)	Frequency (cycles per hour)
K1	61.08	0.156	324	0.0418
O1	25.95	0.101	308	0.0387
P1	6.06	0.049	314	0.0416
M2	3.53	0.0374	323	0.0805
S2	3.37	0.0365	334	0.0833

We then adopted the Eulerian time-mean method to calculate the residual current by averaging the currents during one or more tidal periods:

$$[\bar{u}, \ \bar{v}] = \frac{1}{T}\int_0^T [u, v]dt$$

where u and v represent the eastward and northward components of current; $\bar{u}$ and $\bar{v}$ are the Eulerian residual current; and T is the averaging period, here set to 24 hours given the dominant tidal period is close to 24 hours and the model output is in 2-hour interval. Eight time slots have been selected to investigate the residual currents and water retention time in the period of spring and neap tides (Figure 1). The selected time slots covered the time in a dry month (February) and a wet month (August) in years before and after the construction of the Dawesville Cut (1990 & 1998). Note that the Eulerian time-mean method we used here is relatively simple with primary aim to investigate the current circulation in selected times. Many analytical methods had been proposed to investigate the tide-induced Lagrangian and Eulerian mean circulations in coastal environments (e.g. Cheng, 1996; Pattiaratchi et al., 1996; Wei et al., 2004). But that requires different model settings to our modelling studies and is beyond the current research scope.

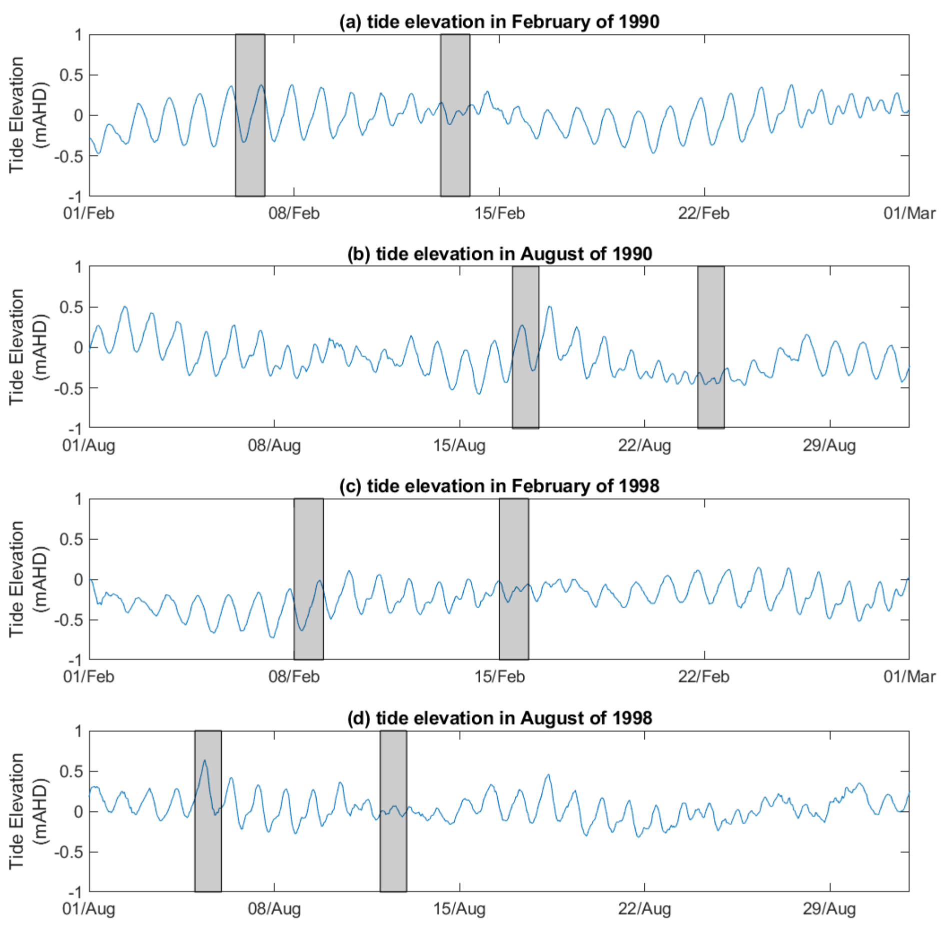

Figure 1. Selected time slots for investigating the spring tide and neap tide on the water retention time. Each time slot spans 24 hours.

The calculated daily residual currents over each time slot at the surface and bottom layers (Figure 2) suggested that the opening of the Dawesville Cut has a strong impact on the residual currents. In the year of 1990, the surface residual currents in the Harvey Estuary were mostly moving northward, and regional-scale residual circulation around the Peel Inlet can be observed. Whilst in the year of 1998, strong residual currents via the Dawesville Cut and occasional circulation around the northern Harvey Estuary are observed. The results also indicated the residual current speeds in the shallow water of the basins were relatively smaller than that in the deeper water.

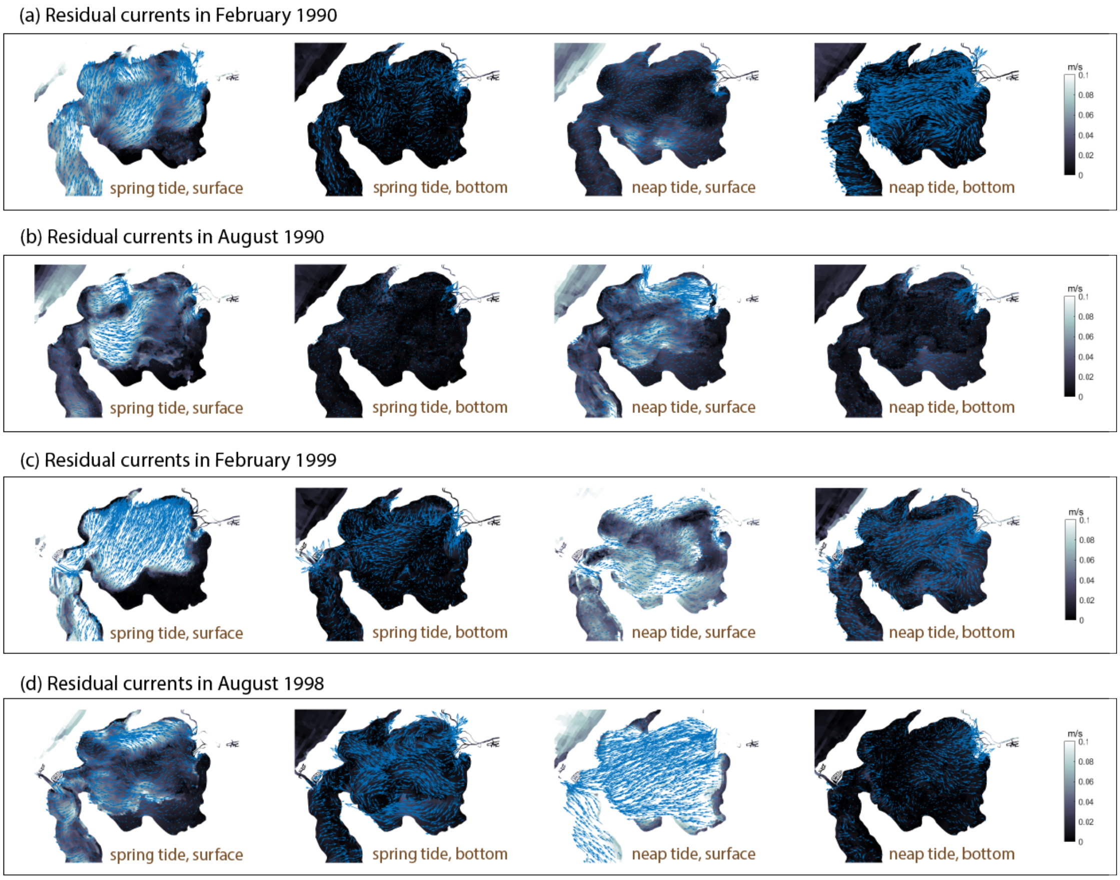

Figure 2. Plain views of daily residual currents in the selected time slots (as indicated in Figure 1). The total current speed is indicated with color scales from 0 – 0.1 m/s.

We further analyzed the impacts of the spring tide and neap tide on the modelled water retention time by averaging the modelled water age in each of the selected time slots (Figure 3). The average water age presented a clear temporal difference between seasons, and a spatial difference between the lagoons. The spatial distribution pattern of the water age is coincident with the residual current, e.g., areas around the channel mouth experienced more flushing, and the shallow water in the basins generally has higher water age than the deeper water.

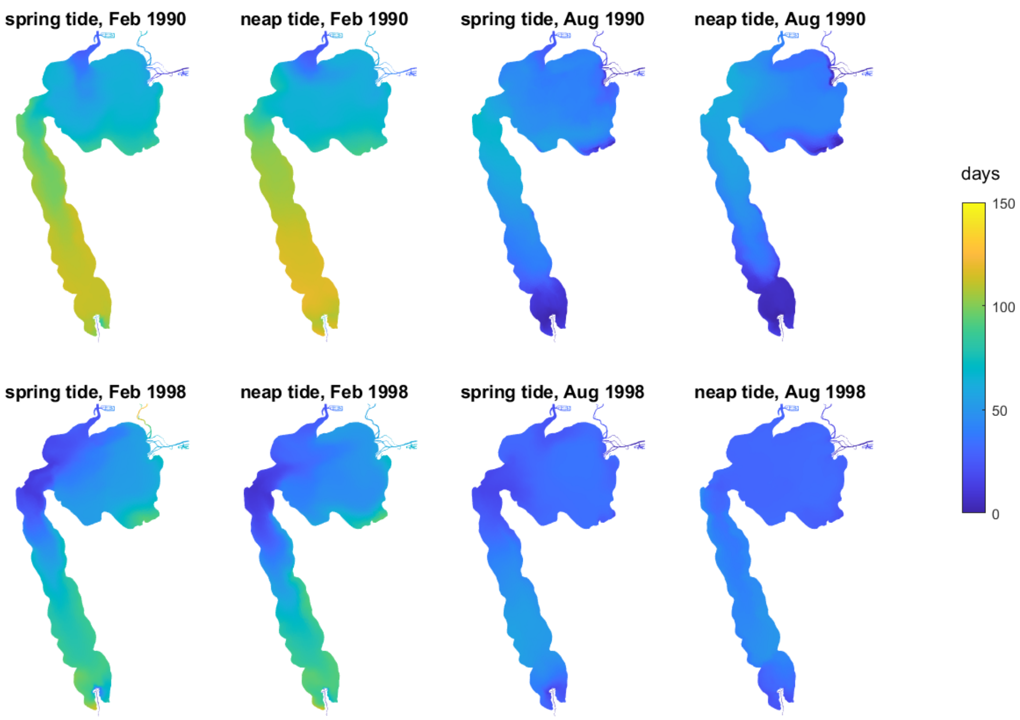

Figure 3. Plain views of average modelled water age in the selected time slots (as indicated in Figure 1).

However, the difference of the water age between the spring and neap tide periods is relatively small when compared to the spatial and seasonal variations. A quantitative comparison of the water age between the spring tide and neap tide periods is shown in Figure 4, which shows the average water age in four areas of the estuary: east Peel Inlet, west Peel Inlet, north Harvey Estuary, and south Harvey Estuary. Note the water retention time is modelled using the 'water age' method, which is the time of a water parcel staying in the model domain since entering the domain from ocean and catchment input, so the impacts of tide excursion on the water age is compounded with the freshwater flushing. In this consideration, the summer time (February) with less freshwater input is more suitable to explore the tide impacts on the water age. In the year of 1990, the maximum difference in the water age in four areas is less than 5 days as observed in the Harvey

Estuary. Whilst in the year of 1998, the maximum difference of the water age between the spring tide and neap tide is about 10 days, as observed in north Harvey Estuary. These results indicate the spring-neap change can affect the hydrology over the short-term scale. However, the difference of water age between the spring tide and neap tide is still small when compared to the impacts of the opening of the Dawesville Cut (~20-110 days) and the reduced flow from 1970 to present (~50-100 days).

In summary, the residual current analysis has been shown to be a useful method to investigate the water transportation and circulation within the lagoons, and to explain the difference of water retention between the shallow and deep water. The results also suggested that the difference of modelled water age between the spring tide and neap tide periods were relatively small when compared to the impacts by the opening of the Dawesville Cut and reduced flow in the past decades. The above discussion on the spring-neap changes in the hydrology will be drafted and added into the manuscript in the revision.

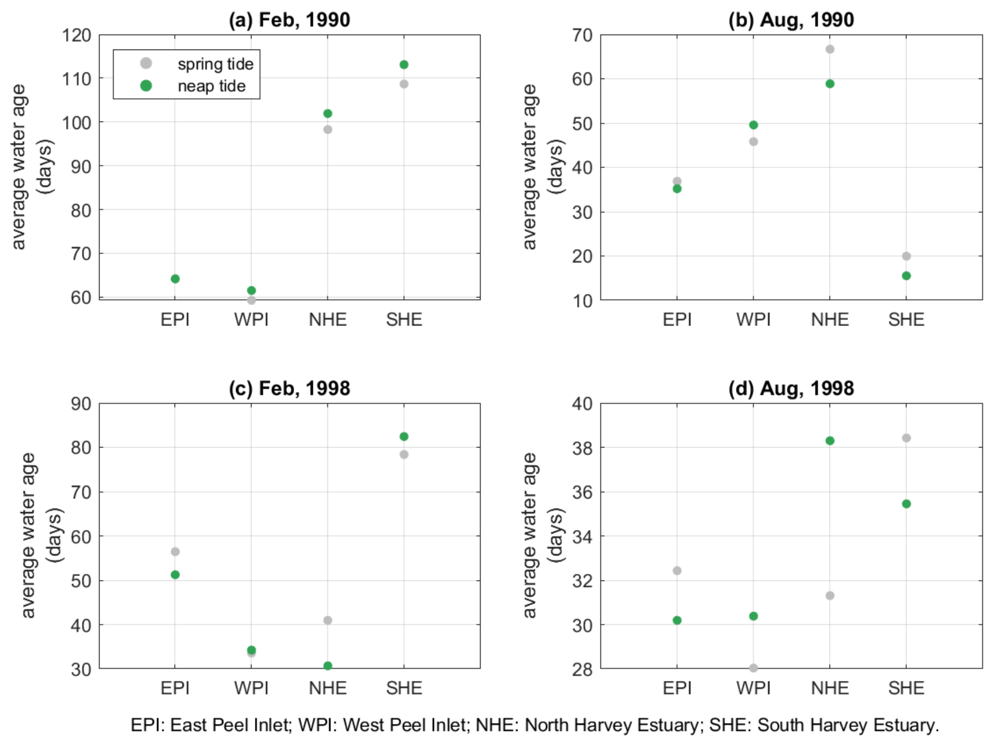

Figure 4. Average water age during the spring tide and neap tide periods for selected time slots in four major regions of Peel-Harvey Estuary: east Peel Inlet; west Peel Inlet; north Harvey Estuary; south Harvey Estuary.

3. It is noted that the morphological change during the study period 1970-2016 is neglected in the hydrodynamical model. It is better to clarify that such an assumption is reasonable.

Response: Thanks for pointing this out. We agree it is important to discuss the morphological changes in the study site as it is a large but shallow lagoon. In the modelling simulations, we assumed there the morphological change over the study period were not significant, except through the construction of the Dawesville Cut. The morphology data we used for the model was the latest morphology dataset from the Western Australia Department of Water, obtained in year 2016 (integrated DEM at 2m resolution).

The estuary morphology over the study period may have been modified by: (1) changes to the net sedimentation of particles; and (2) dredging activities related to marina and navigation channel developments. The net sedimentation rates in the Peel-Harvey Estuary had been investigated by a few early research. Gabrielson and Lukatelich (1985) estimated a net sedimentation rate of about 0.4-1.5 mm/year in the Peel Inlet and 2.9-6.7 mm/year in the Harvey Estuary; Hodgkin et al. (1980) estimated an overall rate of sediment deposition of 0.3 mm/year in the estuary. Assuming the rate is constant, the maximum total sediment deposition is about 75 mm in the Peel Inlet and 335 mm in the Harvey Estuary, over a period of 50 years. Note these rates were estimated in the time before the Dawesville Cut was constructed. After the year of 1994 when the Dawesville Cut was constructed, the sediment deposition in the system, especially in the Harvey lagoon, was expected to decrease due to higher tidal flushing. As we illustrated in the manuscript, a change in the tide elevation of ±0.15m, which could be theoretically equivalent to the change in the depth of the estuary, would have caused a small change to the hydrology compared to that introduced by the opening of the artificial channel and the reduced flow. Therefore we assumed the impact of sediment deposition on the morphology is small. The reduced flow rates over the course of the study period would also lead to a reduction in sediment loading.

The development of canal estates and navigation channels would have further changed the local morphology, but is expected to only slightly modify the estuary hydrology in the regional scale. For example, The Yunderup navigation channel, located at the east side of the Peel Inlet, is one of the more significant dredging projects in the Peel-Harvey Estuary in the past decades. The Yunderup channel has a length of ~3km (mostly in the canal estate and shallow water areas) and a width of ~50m. The total area of this channel is ~0.015 km^2, which is negligible when compared to the area of the east Peel Inlet of 33.5 km^2. We therefore assume the changes brought about by the local dredging activities are negligible in analyzing the estuary hydrology when looking at the average properties over the regions.

We will integrate the above discussion into the manuscript to clarify the assumptions of using the estuary morphology data.

4. Meanwhile, it is worth noting that the water quality (such as salinity and stratification) in the Peel-Harvey estuary was dramatically impacted by the urban development and the agricultural development in the upstream catchments. It appears that the authors also neglect these two factors in the hydrodynamical model. Some explanations can be provided in order to support the current results.

Response: We agree that the catchment development, especially the urban development and the agriculture development will impact the water quality as well as the flows, though we note the urban expansion is mainly on the coastal edge which are minor sub-catchments to the system. We have briefly discussed this point in the manuscript (Section 4.3 – Uncertainty of future hydrology), but we will expand our discussion on the impacts of catchment development on the hydrology and water quality.

Different catchment developments had a combined effect on the flows. For example, the land clearing is expected to increase the streamflow, while local drainage changes have led to water diversions and reductions of the inflows. The Peel-Harvey catchment modelling report (Kelsey, 2011) estimated the land clearing to increase the annual streamflow by 290 GL, while water supply and irrigation dams to decrease flows by 145 GL, and the drain activity to divert about 100 GL, leading to a net increase of about 45GL. The net change in the streamflow is relatively small when compared to the reduced annual flows entering the Peel-Harvey Estuary from 1970 (846.4 GL) to 2016 (514.4 GL). In the hydrologic models we have used the gauged flow data combined with the catchment model outputs, therefore the changes of the flow rates due to the catchment development have been accounted for in the model settings and our analysis. Therefore, we expect the reduced inflow was a key factor of reducing the nutrient loads from catchment, that subsequently reduced the nutrient concentrations in the estuary. We will further clarify this during our revision of the manuscript.

5. With regard to the riverine flow rate reduction, to what extend the river damming affects the river flow? As we know, both the Serpentine and Harvey Rivers are dammed in the upstream catchment.

Response: This is another critical point that need to be clarified of the catchment inflows and we sincerely thank the reviewer for pointing this out.

There are 15 dams in the Peel-Harvey catchment (Table 2). The total catchment area to be dammed is 1,283 km^2, which is about 12% of the total Peel-Harvey catchment (10,671 km^2) (Kelsey, 2011; Hennig et al., in prep). Most of the dams were completed in the time before 1970s when our study period started. The latest catchment modelling results (Hennig et al., in prep) showed that the average annual flow in the years of 2006-2015 from unrestricted catchments was 369 GL/yr while the flow from dammed catchments was 36 GL/yr, which would amount to an additional 10% increase in annual flow if these dams didn't exist. It is understood that no dams in the catchment have planned environmental water releases and it is expected that any water releases would either be a small proportion of flow. All dams except the North and South Dandalup dams have downstream flow measurement that was included in the estuary model. Thus, the effect of dam water releases would be included in the estuary model for the period where there is flow measurement. It is also understood that there are no plans to construct new dams in the catchment due to the considerable reduction in rainfall and streamflow in recent years. New water sources will likely come from unallocated groundwater (<10GL), desalination or wastewater reuse. We will add the above discussion into the manuscript and clarify the uncertainty caused by the dam activities.

Table 2. Dams in the Peel-Harvey catchment. Re-printed from Table 2.4 of the catchment report of Kelsey (2011).

Dam	Completion year	Maximum capacity
Serpentine	1961	137667
Serpentine Pipehead	1957	2625
North Dandalup	1994	74849
North Dandalup Pipehead	1970	
Conjurunup Pipehead	1992	180
South Dandalup	1974	130000
South Dandalup Pipehead	1971	
Waroona	1966	15173
Drakes Brook	1931	2290
Samson Brook	1941	7993
Samson Brook Pipehead		
Logue Brook	1963	24321
Stirling	1948	53769
Stirling Pipehead	1920	
Harvey	1916	56441

Some Minor concerns:

Thank you for these suggestions, we will update all these in the revision.

1. In the title, 'hydrologic'→'hydrological'?

Response: Comment accepted.

2. It is better to use the SI units for the whole paper. For instance, replacing GL with m3 for the volume.

Response: Comment accepted. We will check through and use the SI units consistently in the manuscript.

3. Figure 1: Add the north arrow and define the 'mAHD' in the main text.

Response: Comment accepted.

4. Line 150: It is better to define the water age τ before mentioning it.

Response: Comment accepted.

5. Lines 252-253: Why using 1990 and 1998 for a comparison? It is better to clarify the choice.

Response: The reason to use 1990 and 1998 for a comparison is that they are two closest years in all the selected modelling years to the year of the opening of the Dawesville Cut in 1994. They also had similar seasonal signals in the catchment inflows, and similar average tide elevation over the year. So we have selected these two years to illustrate the impacts of the Dawesville Cut without these other confounding factors, and to demonstrate the capability of the model to capture the changes in the hydrological features. We will add the explanation in the revision to clarify the use of the two years.

6. Figure 8: It is better to show some contour lines indicating the exact numbers.

Response: Comment accepted.

7. Figure 9 and Figure 11: the color is not easy to distinguish.

Response: Comment accepted. We will adopt a better color scheme for these figures.

8. Lines 471-472: It is better to define the TN and TP before using the abbreviations.

Response: Comment accepted.

Reference:

Codiga, D.L., 2011, Unified Tidal Analysis and Prediction Using the UTide Matlab Functions. Technical Report 2011-01. Graduate School of Oceanography, University of Rhode Island, Narragansett, RI. 59pp. ftp://www.po.gso.uri.edu/pub/downloads/codiga/pubs/2011Codiga-UTide-Report.pdf

Kelsey, P., Hall, J., Kretschmer, P., Quinton, B. & Shakya D., 2011, Hydrological and nutrient modelling of the Peel-Harvey catchment, Water Science Technical Series, Report no.33, Department of Water, Western Australia.

Gabrielson, J.O., & Lukatelich, R.J., 1985, Wind related resuspension of sediments in the Peel-Harvey estuarine system. Estuarine, Coastal Shelf Science 20, 135–145.

Hodgkin, E.P., Birch, P.B., Black, R.E., and Humphries R.B., 1980, The Peel-Harvey estuarine system study, Report no. 9, Department of Conservation and

Environment, Western Australia.

Pattiaratchi, C., Bowman, M. J. (Ed.), & Mooers, C. N. K. (Ed.), 1996. *Mixing in Estuaries and Coastal Seas*. Washington, D.C.: American Geophysical Union.

Wei, H., Hainbucher, D., Pohlmann, T., Feng, S.Z., Suendermann J., 2004, Tidal-induced Lagrangian and Eulerian mean circulation in the Bohai Sea, Journal of Marine Systems, 44 (2004), pp. 141-151.

Cheng, R., 1990, Residual currents and long-term transport. Springer, Berlin, 544 p.

Hennig, K., Kelsey, P., Hall, J., Gunaratne, G.G., Robb, M., in preparation, Hydrological and nutrient modelling of the Peel-Harvey estuary catchment (2006–15), Water Science Technical Series, Aquatic Science Branch, Department of Water and Environmental Regulation, Perth, Western Australia.