Response to interactive comments from Anonymous Referee #1 on "From days to decades: numerical modeling of freshwater lens response to climate change stressors on small islands" by S. Holding and D. M. Allen

Reviewer: This is an interesting paper that aims to identify critical factors and stressors that may affect freshwater lenses on Andros Island and other small, low-lying islands of a similar hydrogeological setting. Specifically, the paper explores the impact of storm surge over-wash, sea-level rise and recharge change using the density dependent numerical groundwater modeling codes HydroGeoSphere and SEAWAT. A physically based soil drainage model (HELP) is used to estimate recharge under current conditions and future climate change scenarios. The paper is very well written. The study site is described in sufficient detail as is the development of the models. The work is technically sound and, for the most part, achieves the objective. Clarification is required in areas outlined below.

Response: *The authors thank the reviewer for his/her helpful comments and suggestions, and particularly for identifying areas requiring clarification. Each review comment is addressed below*.

Specific comments:

Comment 1) 11440L6 HydroGeoSphere was used to account for unsaturated zone processes, as opposed to differences in spatial or temporal scale. Please modify the sentence starting with 'To account for: : :'.

Response: HydroGeoSphere was primarily used to account for the unsaturated zone processes, although the two different modeling codes were also used to address the varying spatial and temporal scales. The sentence is amended to: "To account for the varying spatial and temporal scales of the stressors, two different density-dependent flow and solute transport codes are used: SEAWAT (saturated) and HydroGeoSphere (unsaturated/saturated).

Comment 2) 11440L14 If space permits, please add that a flux-controlled conceptualisation applies to the Andros Islands, which limits the impact of sea-level rise. Also, to clarify the sentence about response times, a statement could be added about lens response times increasing as sea-level rise and recharge change increased. The method of implementing the changes (i.e., incremental instantaneous shifts) could also be noted.

Response: Additional content has been added to the abstract, beginning at Line 10: "Simulations of reduced recharge result in a greater loss of freshwater lens volume (up to 19%), while sea level rise contributes a lower volume loss (up to 5%) due to the flux-controlled conceptualisation of Andros Island, which limits the impact of sea level rise. Reduced recharge and sea level rise were simulated as incremental instantaneous shifts. The lens responds relatively quickly to these stressors, within 0.5 to 3 years, with response time increasing as the magnitude of stressor increases."

Comment 3)11448L8 What value of specific yield and porosity were applied? Table 1 lists only the specific storage. Were the model layers set as unconfined or confined? The response times will be highly dependent on the storage parameters, and the freshwater volume will be proportional to the porosity, so it is important to list these and comment on the accuracy and possible range of these values.

Response: The aquifer is unconfined. Suggested addition to 11444L22: "The principal aquifer is the unconfined Lucayan Limestone…". Effective porosity has been added to Table 1. The value

(0.15) is based on the field observations of total porosity (ranging from 0.1-0.2, presented in 11445L16). Specific yield is also added to Table 1 (0.2). Storage parameters were derived as estimates based on the aquifer lithology. Text has been added to 11449L16, after sentence ending in Table 1, as follows: "Storage parameters were based on common values for the aquifer lithology (Younger, 1993)." New reference for Younger, 1993 is also added to reference list: Younger, P.L.: Simple generalized methods for estimating aquifer storage parameters, Quarterly Journal of Engineering Geology and Hydrogeology, 26, 127-135, 1993. doi: 10.1144/GSL.QJEG.1993.026.02.04

Comment 4) 11449L11 Please also list the maximum and minimum recharge values predicted by HELP and the months in which these occurred.
Response: The value cited is the average annual amount throughout the 100 years simulated. Average monthly minimum and maximum values have been added to the sentence as follows: "The average annual recharge was estimated at 877 mm/year for the north, with a minimum monthly average of 24 mm in December and a maximum monthly average of 163 mm in August. The average annual recharge was estimated at 426 mm/year for the south, with a minimum monthly average of 17 mm in February and maximum monthly average of 70 mm in October.

Comment 5) 11449L16 The wellfields are not included in the model being used to explore the impact of sea-level rise and recharge change. From Figure 1 there are numerous trench wellfields along the east of the island and close to the coast. Please discuss the likely impact of not including the wellfield on the analysis of sea-level rise and recharge change. Do the wellfields impact on the ability of the water levels to rise in the aquifer (i.e., because the water in the trenches evaporates or is extracted)? If so, head-controlled conditions may occur in these areas, which will increase the impacts of sea-level rise compared to the flux-controlled conceptualisation used in the model.
Response: The actual area of open trench is very small relative to the freshwater lens and so any potential head-controlled conditions would be highly localised around the trench and not likely to have a measurable impact on the lens volume at the scale of the models. Additionally, the wellfields are not likely to affect lens volume significantly due to upconing. For example, when the wellfields were evaluated in smaller-scale pumping models, there was little upconing observed at the current pumping regime. A sentence has been added at 11449L16 to address this: "Given their small size, the wellfields are not anticipated to affect the freshwater lens response. If the system were head-controlled, however, at a local scale a rise in water table could result in more loss of freshwater from the top of the lens."

Comment 6) 11450L14 Please list the new recharge values including maximum and minimum values and months they occurred in.
Response: New sentence added on 11450L15: "The predicted average annual recharge for the north was 777 mm/year, with a minimum monthly average of 18 mm in March and a maximum monthly average of 130 mm in August. The predicted average annual recharge for the south was 360 mm/year, with a minimum monthly average of 4 mm in July and a maximum monthly average of 82 mm in November"

Comment 7) 11450L19 What was the average loss of land surface, especially along the east coast where the wellfields and settlements are located?
Response: Loss of land-surface was evaluated based on land elevation using GIS (publication under review). There was no loss of land surface along the east coast due to the steeply rising topography. Text has been added to the Discussion section, as outlined in the response to Comment 16.

Comment 8) 11451L4 Please replace incremental shifts with incremental instantaneous shifts, or similar.
Response: All instances of "incremental shifts" are replaced with "incremental instantaneous shifts".

Comment 9) 11451L22 The use of GIS analysis to calculate lens area and volume is a nice approach. The resulting figures are very nice. Please add details of whether the aquifer porosity was included in the volume calculations.
Responses: Thank you. Aquifer porosity was included in these calculations, so the results represent the volume/area of the freshwater lens, not the aquifer. The sentences have been edited as follows: ''The volume and area of the lens were calculated based on a threshold salt concentration 0.4 g/L or less (representing local potable water guidelines) and porosity. Although there are inaccuracies inherent in this approach, it provides an estimate of the lens morphology that allows for quantitative comparison of the changes in freshwater lens morphology between different stressors applied in the island-scale model"

Comment 10) 11455L4 'Most" implies that some did not, please clarify.
Response: This is referencing Phase 2 simulations that were run to address the discrepancy between observed data and model results (11462L8). To avoid confusion in the methodology, this sentence has been changed to "All".

Comment 11) 11457L5 A thin lens is not present throughout most of the domain because Figure 5 shows that the lens is thick in areas. Please rephrase this sentence.
Response: The thin lens was referring to the areas not presented in Figure 5. The sentence has been amended, with "thin" removed: "The model results indicate that a lens is present throughout most of the model domain; however, this study focuses on areas considered viable to provide…"

Comment 12) 11457L12 Is the given volume the volume of aquifer or the volume of freshwater? Please clarify.
Response: This refers to the freshwater lens volume (accounting for porosity). The sentence is amended for clarification: "The estimated total area of the viable freshwater lens on Andros Island is approximately 2,000 km^2 with a fresh water volume of…with an aquifer volume of…."

Comment 13) 11459L9 Please add the change in volume associated with recharge change and sea-level rise for the north island.
Response: The sentences are amended starting from 11459L7: "The freshwater lens in the southern model is predicted to incur a greater percentage of loss of lens compared to the northern model under climate change conditions. In the southern model, the results indicate a 19% volume loss due to reduced recharge compared to 5% volume loss due to sea level rise relative to baseline morphology. Whereas, in the northern model, 5% of volume loss is due to reduced recharge with 0.9% volume loss due to sea level rise."

Comment 14) 11460L9 Table 3 does not contain calibration criteria, rather model parameters, please amend.
Response: Yes, indeed. The text and table have been modified to clarify that observed conditions were used for calibration. The sentence is amended: "The model is calibrated to the observed conditions outlined in Table 3." The title of Table 3 is also changed to: "Observed conditions used for calibrating the HGS model"

Comment 15) 11461L19 Please explain the cause of the temporary rise in relative concentration, most clearly shown for Drain Day 1 in Figure 10.
Response: As the trench is drained and all the water removed, the concentration decreases, but when the draining stops (at Day 2), the water from the surrounding aquifer (which includes the still flooded vadose zone) re-enters the trench and causes an increase in concentration again. The following text is added to the caption for Figure 10 to address this: "The small increase in concentration observed for Scenario Drain Day 1 represents the end of the draining period, when high concentration water re-enters the trench from the surrounding aquifer and vadose zone."

Comment 16) 11463L12 It should be stated somewhere in this paragraph that land surface inundation was not considered in the analysis. The results may well be different if it were, and so it is important to be explicit about this.
Response: Land surface inundation was estimated based on ground surface elevation, which indicated that loss of land surface (and resulting loss of freshwater lens volume) was small. These results are presented in a different publication (under review) that show limited land-loss anticipated in areas that the lens is present. The following sentence is added at 11462L14 for clarity: "Although loss of land surface due to sea level rise was not simulated in the models, estimates based on ground surface elevation suggest loss of land surface (and resulting loss of freshwater lens volume) is limited. On islands with lower topography and/or smaller land area, inundation would have a greater effect on loss of freshwater lens volume. The model results for Andros Island are supported by other studies, which show that conditions of reduced recharge….."

Comment 17) 11464L20 It is interesting that the lens have a larger response time as the magnitude of sea-level rise and recharge change increased. Is there a physical explanation for this? Does the work of Stoeckl and Houben (2013) offer further insight, at least for recharge change?
Response: As the magnitude increases, this results in a lower recharge rate to the system. Therefore, the whole system is slower to respond, and the response of the lens to any changes is slower. This is the main conclusion regarding the observation in Stoeckl and Houben's work. If increased magnitude of change resulted in higher recharge rates, it would be anticipated that the system would respond more quickly. This was discussed on pg. 11464 L17-L20, although no further insight is provided.

Comment 18) 11466L1 What element of the analysis forms the basis for conclusion 1?
Response: This statement is based on the observation that the loss of lens under the stressor scenarios occurred primarily along the edges of the lens (shown on Figure 6). In addition, the loss of lens area indicates that the lens is shrinking, not just thinning (as would be the case if the volume changed, but the area remained constant). A shrinking lens indicates that the impact of stressors would be most drastic along the edges. The following statement was added to the results section (11459L2 after sentence ending in "..Table 5..") for greater clarification: "The change in area and volume of the lens indicate that the lens shrinks and thins in response to the stressors." Additionally, text was added to the Discussion section to expand on this 11463L12: "The volume and area of the freshwater lens are reduced under stressed conditions, indicating that the lens both shrinks and thins. A significant impact is observed in areas where the lens shrinks (i.e. along the periphery), as most settlements and related infrastructure are typically near the coast on small islands (Ranjan et al., 2009; Cashman et al., 2010). As a result, any changes in the freshwater lens morphology within the coastal zone may affect access and availability of fresh water near the population centres."

Comment 19) 11466L8 Please rephrase as ‘Reduction in groundwater recharge to Andros Island is identified: : :’. The analysis shows that it produces more impact than sea-level rise on Andros Island but this may not be the case elsewhere, for example on islands that are topographically limited and where sea-level rise causes large land surface inundation.
Response: sentence amended following your suggestion: “Change to groundwater recharge is identified as a key stressor to Andros Island, where greater impacts…”

Technical comments
11467L15 Behzad, A. A. needs to be replaced with Ataie Ashtiani, B.
Response: Thank you for spotting that. This has been changed in the text and reference list.