DATE : 30-01-2015

DOCUMENT : M-1431-02

REVISION : 1

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CLIENT: AN BOARD PLEANÁLA

TITLE: Galway Harbour Extension - Review of Marine Hydrology Issues

Contents

1 INTRODUCTION

An Bord Pleanála has requested Principia North with specific appointment of Professor Jorgen Fredsoe to provide support for the evaluation of the extension of Galway Harbour Extension.

This review focusses on how the impact of the proposed extension of the Galway Harbour has been addressed within Marine Hydrology in the Environmental Assessment Studies (EIS). Special attention has been given on A: whether the existing nature of the receiving environment has been described adequately and B: Whether mitigation measures to avoid major adverse effects adequately has been set out.

The EIS within Marine Hydrology assesses the following issues:

- Flood Risk.
- Sedimentation and erosion patterns in the Harbour area
- Impact from dredging during the construction phase and during maintenance dredging.
- Potential changes in salinity in Lough Atalia and Renmore Lough and in the near shore areas.
- Potential impact on effluent dispersion from Mutton Island outfall and the proposed Galway outfall.

Literature applied in this review:

The marine hydrology is mainly described in Ch. 8 of the EIS /1/ with an additional part /2/, in which the additional information requested by An Bord Pleanala was responded to by the applicant. All Marine Hydrology findings are summarized in /S1/, which was presented at the Oral Hearing in Galway, Jan. 13th 2015. Due to the existence of this detailed review, the findings in the present review are only included if necessary for the evaluation of the EIS.

Ch. 6 in the EIS on soil /1/ contains a section on Capital and Maintenance dredging (also briefly described in Ch. 8, /1/)

Additional detailed literature /3/ and /4/ by Aquafact on dispersion and salinity are also included, because they incorporated details not originally included in the EIS /1/ relating to model description and measurements.

2 REFERENCES

/1/ EIS: Galway Harbour Company: Galway Harbour Extension, Environmental Impact Statement.

/2/ EIS Addendum, Response to request for further information.

/3/ Aquafact: A report on A9 Ecological, Oceanographic and Modelling Studies in Lough Atalia and Renmore Lough, Inner Galway Bay in relation to their status as a Priority Habitat within the EU Habitats Directive and B9 The effects of the proposed Galway Harbour extension on the Lough Atalia and Renmore Lough.

/4/ Hydro Environmental Ltd: Dispersion Modelling Of Salinity in Inner Galway Bay and Lough Atalia for the Galway Harbour Extension Project. Rep. no HEL098001v.1.

Submissions to the An Bord Pleánala Oral Hearing, Jan. 2015.

/S1/: A. Cawley: Marine Hydrology and Flooding, Brief of Evidence.

/S2/: Environment agency : Adopting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities. Submission for the Oral Hearing.

/S3/: Cladonian Mariners Community Boat Club, Submission for Oral Hearing.

/S4/: Brendan O´Connor: Witness Statement for Galway Harbour Extension.

3 OVERALL CONCLUSION

The EIS /1/ constitutes together with /2/ a profound and sound hydrodynamic numerical analysis of flood risk, sedimentation problems and dispersion of effluents.

The proposed extension is assessed to have the following impacts:

Deflection of the out- and in-going flow of water in the bay near River Corrib into a more North-Southerly direction, where the proposed Marina Breakwater acts as a guiding wall. This breakwater will also reflect incoming wind waves mainly from SW to increase the wave heights in front of Nimmo´s pier by up to 15 cm during storms, while the similar increase at South Park is not more than 5 cm.

Increased shelter especially in the Bay eastwards of the proposed extension against wind waves from Westerly directions. Also as the eastern section of the Bay will be partly sheltered from the outflowing fresh water from the River Corrib, the water here will be slightly more saline. This sheltering effect will also lead to a very slight increase of effluent during wind from S in the harbor area including Lough Atalia because the effluent will be guided along the Marina Breakwater into the harbor area.

All impacts are easily understandable from a physical point of view, and are satisfactory explained in the EIS.

Some *minor* issues can still be raised, which by no means will change the main conclusions of the study.

The main issue is that more information could have been derived from the field data to increase the reliability of the model predictions. This concern is mainly related to wind wave and sediment transport predictions. Actually no wave measurements are presented in the near harbour area to test the numerical predictions.

Also it has not been clearly stated in the report that no accumulation of sediment has occurred west of the Mutton Island Causeway. If this really is the case, we are dealing with a starving bed, i.e. a bed where loose transportable sediment only is partly present in the bed, the rest being either solid or covered by vegetation. This actually will lead to different sediment pattern than those predicted in the report.

Finally the wind set-up due to strong wind from SSW and SW next to the one presented coming from S should be shown in the near harbor area to scan a larger window of incoming wind impact on the set-up.

4 HYDRODYNAMICS AND HYDROLOGY OF THE BAY

The near Galway Harbour area is dominated by tide with a tidal range varying from 1.9 m (neap) to 4.3 m (spring), /1/ Ch. 7, p. 7-1. Next to the tide there are wind driven currents and wind set up (storm surge), wind waves and fluvial flow, the latter being totally dominated by the flow in River Corrib.

The wind waves can be categorized into two groups: large Atlantic swells, and locally (in the Bay generated) shorter period waves. Because of the partial blocking of the bay entrance by the Aran Islands, the Atlantic waves are relatively small in height. In the near harbor area, the wave heights hardly ever exceed 2 meters.

The discharge in the River Corrib is in mean 82 cbm/sec (cubic metres per second), with a summer minimum flow of 25-50 cbm/sec, and a Winter maximum of 250-300 cbm/sec , /1/ Ch. 7, p. 7-1.

The bay is shallow with water depths mainly lower than 20 meters.

The proposed extension extends almost one kilometer into the Bay, and the location could be sensitive due to two impacts: partly the location is just next to the largest outflow of fluvial flow (from Corrib River), which locally will change the salinity distribution. Next to that, the harbour may act as a long jetty, trapping parts of the longshore sediment. The latter impact is reduced, because of the presence of the already constructed Mutton Island Causeway.

5 FLOOD RISK

5.1 SCOPE:

To study whether the proposed extension will cause increased water levels or higher risk for overtopping at exposed areas. The principal flood risk areas are listed in /1/ section 8.4.7.3 and a map is included in /2/ p. 132, fig. 4.10.1.

Land below 4.2 m O.D.Malin is considered to be the main flood risk areas at present conditions, /1/ 8.4.7.3. This corresponds to a 200 year tide of 4.146 m with additional freeboard allowance. If an additional 500mm climate change is included, this gives in total 4.646m.O.D. Malin or 4.7 m with additional freeboard allowance. These two elevations are shown in figure 4.10.1 /2/. In /3/, section 3.4.4., flood zones A and B are more specifically defined, and by combining /2/ and /3/ you get that zone A is the high Flood Risk zone representing lands that are below the 100-Yr fluvial flood level or 200-Yr tidal or tidal-fluvial flood level. Zone B is a moderate coastal flood area, 4.7 m O.D. according to fig. 4.10.1 /2/

5.2 PROBLEM FORMULATION:

Additional flooding due to the Harbour Extension may be due to

A: Local increase in water level during high tide and storm surge because the reclaimed area (23.89 ha, EIS ch.4, p4-4) displaces an area which previously accommodated the seawater.

B: Change in the wind wave pattern due to reflection from the new proposed breakwaters and refraction of the wind waves due to changes in the flow current patterns by the proposed extension.~~.~~ Also, the proposed extension will provide sheltering effects on the lee side of the breakwaters, which is favorable in terms of decreasing the flood risk by wave overtopping.

C: Increased flow resistance to the outflow from Corrib River from the extension (by blocking of part of the inner bay).

D: Increased wind set-up at the inner part of the harbor area W of the proposed extension due to funneling.

The critical conditions for flood risk is (cf. p.8-162, /1/) a combination of tidal flooding, fluvial flooding (from The Corrib River) and wind wave overtopping.

5.3 ASSESSMENT:

The assessment is described in section 8.4.7 /1/. The assessment is based on the use of well-established numerical/mathematical modelling in combination with available field experiments.

5.3.1 Available field data used for the assessment:

Water levels:

The numerical model requires data input at the model borders to force the flow: at the Westerly border in the open (Atlantic) sea, the forcing tide is specified. The fluvial border is specified at Wolfe Tone Bridge. All other fluvial inflow is considered insignificant. Finally, wind shear along each surface nodal point is specified. (p. 8-9, /1/).

Water level and storm surge statistics are both based on existing statistics as described in section 8.4,7,7 of the EIS - “Flood Hydrology and Tides”. Gauge measurements at Oranmore Bridge are available since 1982, and provide data for statistical behavior of the combined tidal and storm surge water elevation. The statistical predicted 200-year flood elevation becomes 3.80 m O.D. at Oranmore Estuary Gauge.

At Wolfe Tone Bridge, gauge recordings are available in the period 1982 to 2006, and here the 200-year flood elevation prediction becomes 3.96 m O.D. At Wolf Tone Bridge you have a combination of tidal flow and freshwater supply (fluvial flow), and the Corrib Fluvial Flood Flow is estimated by extrapolation by extracting the flow at non-tidal periods. (p 8-173). The estimated 100-year flood flow peak for the River Corrib is estimated to be 421 cbm/sec, p.8-177 in /1/.

Future climate changes are not directly relevant for the impact of the proposed extension, but are anyway included in the assessment of future flood risk. Due to climate changes, an increase by 20% in the peak flow rates in River Corrib are recommended to be included in future assessment of flooding issues, cf. p 8-178 /1/. A sea level rise of around 0.5 m is considered to be a medium range climate change scenario, /S1/ section 3.4.4.

Wind waves:

No wind wave measurements in the bay are incorporated in the EIS. Instead the waves are hindcasted (that is, a statistical calculation determining probable past conditions) from wind data. These hindcasts are based on the wind data from the Belmullet monitoring station, which is the closest monitoring station to Galway Bay. The data evaluation is based on 50-years recordings of wind speed and direction, p. 8-126 /1/.

Regarding the local wave analysis, this is based on wind data provided by the Irish Met service, p. 8-137 /1/.

5.3.2 Hydrodynamic modelling simulations:

Flow pattern:

The flow can be impacted by the proposed extension in two ways:

- The tide and storm surge in combination with the outflow from Corrib River will be affected,
- The wind waves in the area will be slightly altered.
- Tidal flow, River flow and storm surge:

The impact of the suggested extension has been studied by using a numerical flow model (TELEMAC-2D). 2D stands for two-dimensional, because the real 3D- flow is depth- integrated. Variations in flow velocity therefore only occur in the 2 horizontal directions. This is standard when calculating this kind of homogeneous flow over large areas.

A number of different scenarios have been selected and a comparison has been done of flow velocities and water levels before and after the proposed extension. The scenarios comprise (/1/ p 8-179):

- 100-Yr Corrib Flood Flow combined with mean spring tide
- 100-Yr Corrib Flood Flow combined with Historical Maximum Storm Surge Tide
- 100-Yr Corrib Flood Flow included additional 20% due to climate changes combined with Historical Maximum Storm Surge Tide

- 100-Yr Corrib Flood Flow included additional 20% due to climate changes combined with 200-Yr design tide level.

Wind Waves:

- Wind waves are treated independently from tide and fluvial flow in /1/(p 8-135 to p 8-159). The wave properties are hindcasted from wind measurements at Belmullet monitoring station (p. 8-136), and the waves are calculated using a Boussinesq approximation (depth-integrated, using the code TOMAWAC). In the near harbor area, /1/ uses another depth integrated model ARTEMIS. In this part of the investigation, the interaction between the waves and current (wave refraction) is not included.
- In /2/ this has been accounted for applying a spectral model (SWAN).

The wave pattern is described for the following scenarios:

- A 50 Yr. wind with directions from W, WSW, SW, SSW,S, SSE,SE, ESE and E.
- Additional runs have been done using an (artificial, i.e. not predicted) higher water depth of 4.63 m O.D. Malin). This has been done to evaluate the sheltering impact of the Mutton Island Causeway, which at lower water levels has a significant reduction of waves along the coast from the head of Nimmo's Pier to the Renmore Shoreline area. At the higher water level (4.63m O.D.) the Mutton Island Causeway is exposed to wave-overtopping.

In general, the wave heights are moderate (always less than 2 meter in height), partly due to the Aran Islands, and partly due to the relatively shallow water in the Bay (p 8-143).

5.4 MAIN RESULT:

The EIS presents two kinds of hydrodynamic results, namely

- Velocity plots (figure 8.4.152 to 8.4.183 in /1/)
- Water level plots (figure 8.4.184 to 8.4.208 in /1/)

The velocity plots are commented on later, section 3 in this review.

Water levels due to Tidal flow, River flow and storm surge:

The numerical results illustrate that virtually no change occurs in water levels at 6 selected reference sites at selected locations in or near the harbor area, depicted in figure 8.4.184. Especially at high tide, hardly any changes can be detected. At low tide, slightly larger impact of the harbor extension can be seen, but this is not relevant regarding the flooding issue.

(The reason for this very small impact is that the rise and fall of the tidal wave is so slow, that the water brought into the site by the tidal motion has sufficiently time to flow to the surrounding bay areas, when the proposed extension will displace parts of the bay area).

Further, the output of the four combinations of tide and fluvial flow listed above is discussed in section 8.4.7.9.4 p. 8-182 in /1/: By comparing the different runs it turns out, that within the areas exposed to flood risk, the peak water levels produced by a tidal surge will be virtually the same independently of the magnitude of flow in the River Corrib. This means that the flood risk to Claddagh, Spanish Arch and docks area is due to a tidal storm event and not to the flow from river Corrib.

Wind waves:

The main impact from the proposed extension on wind waves are

- Partial reflection of incoming waves from the Marina breakwater, which will make Nimmo´s Pier and Southern Park slightly more exposed at some wind directions, and
- Sheltering effects behind the proposed extension.

The key result is presented in Fig. 8.4.140/141 in /1/and in figure 4.4.42 in /2/, which depict the computed highest wave heights for all the incoming wave directions listed above for existing and proposed cases. This highest wave is depicted along the relevant stretches impacted by the proposed extension. The impact of waves are (as stated p. 8-135) “flooding by wave over topping combined with high water tide”

The only significant *increase* in wave height due to the proposed extension is along the middle of the Nimmo´s pier and a short part of the adjoining South Park, where the increase in wave height predicted by the ARTEMIS-model can be up to 15 cm under Atlantic storm directions SSW to WSW. On the other hand, the SWAN-model do not predict any increase along South Park and Nimmo´s Pier.

A positive impact is, that the maximum wave heights in the harbor entrance East of Nimmo´s pier are significant decreased, again with reference to figure 4.4.42, /2/. The cause for this reduction is that the largest waves in the entrance are produced by wind waves from the SSE and SE sectors, so sheltering from the proposed extension will lead to less impact in the entrance from these directions (section 3.2.6, /S1/).

Impact of Wave Roughness:

One important calibration parameter for the flow modeling is the bed roughness, which modify velocities and water levels: an increased bed roughness will increase the flow resistance and thereby decrease flow velocities, and increase water levels. Larger roughness can be caused by irregularity in the bed (small scale bed forms like ripples) or by an increased near bed turbulence (wave roughness) caused by the wave orbital motion.

For this reason the model predictions are performed in /2/, section 4.6.2 with different roughness’s. The roughness sensitivity is studied at five locations, figure 4.6.1, and the most important point being reference point 1, which is located in the Claddagh basin. Figure 4.6.2 depicts the water elevation sensitivity to roughness here, and a larger roughness actually increases the water elevation at high tide with approximately 10 cm. However, the key figure 4.4.42 shows that the wave action in the channel actually becomes *smaller* after the extension, so the wave-roughness will actually *decrease* after the extension, thus lowering the risk of flooding.

5.5 COMMENTS ON THE FLOOD RISK ASSESSMENT

Some minor comments are given below, which will have no impact on the conclusions arrived in the EIS:

Water levels: Regarding calibration: It is not very transparent how the numerical model is calibrated. Section 8.2.2 mentions some earlier studies of the flow in the bay, but no comparisons between these data with the model predictions are given.

The tide flow and storm surge based on gauges at Oranmore Bay at old Dublin Road Bridge are properly incorporated in /1/.

Wind waves: The key figure 8.4.141 has no validation from existing measurements. The predictions of wind waves are quite indirect applying the Shore Protection Manual method. It could be useful to compare predictions of the hindcasted waves with some wind wave measurements nearby the Corrib entrance during the existing storm conditions. Since no calibration has been performed, this part of the analysis can't predict *absolute* values very accurately, while differences due to the proposed extension still are properly evaluated.

Overtopping by wind waves: The risk of overtopping depends not only on the incoming wave height but also on the incoming angle of the wavefront relative to the structure and also on the slope of this structure. This should have been evaluated in more detail in the EIS. The reflection of waves is most likely responsible for what in /S3/ is called more "vigorous water movements" West of the Mutton Island causeway after its construction.

Future changes in wind wave pattern: /S4/p. 16 points out, that future storm track over UK are quite uncertain, therefore storm surge and wind wave hindcast might be uncertain. This uncertainty should be commented on in the EIS.

Fluvial flow: The high scenarios for the fluvial flow at Wolfe Tone Bridge are properly incorporated. Regarding the 20 % increase in the 100-Yr Corrib Flow due to future climate changes, this is more conservative than explained in /1/ since most of the flow runs through Lough Corrib, thus reducing the peak values of the fluvial part of the flow. Also the river flow can be adjusted by gates, which further can reduce the peaks in the flow. In the submission from An Taisce which refers to the Publication by the UK Environment Agency, entitled 'Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authoirities' /S2/,p. 27, it is pointed out, that "20% allowance no longer encompasses the majority of catchment changes in flood flows using UKCP09 climate projections." However, this is for two reasons not a major concern: partly due to the conservatism in the estimate as outlined above, and partly because the fluvial flooding contribution only constitutes an insignificant contribution to the flood risk. As stated in /S1/ section 3.4.6, the critical condition for the harbor development is the 200-year tidal storm surge, and not a combined fluvial and tide flow event.

Wind shear: The impact of wind shear is small according to figure 4.6.13 in /2/, and no funnel effect due to the proposed extension can be observed. In this plot the wind is coming from S and therefore is almost parallel to the proposed extension. Other directions like SSW might give a slightly higher impact, but such difference plots in predicted peak flood levels are not presented.

5.6 MITIGATION:

The only impact is at the entrance to the walkway at Nimmo´s Pier, which will be exposed to slightly higher waves, up to 10-15 cm higher due to the proposed extension.

No mitigation measures have been suggested, and are not necessary since the shoreline here is raised (cf. section 3.2.6, /S1/)

5.7 CONCLUSION:

The assessment of changed flood risk due to the proposed extension is basically sound and of high quality. The numerical modeling is adequate, and the numerical model system is of high international standard.

The selected number of scenarios for wind, tide and River flow has been selected properly to cover any situations, at which flood risk might be increased due to the proposed extension.

The approximations behind the modelling (such as the assumption of steady flow in Corrib River, reflection coefficients chosen for the breakwaters, inclusion of climate changes) are reasonable. The extent of the model area included in the modeling is appropriate.

The met-ocean data applied as input to the modeling assessment are selected appropriately.

The absolute predictions of wave heights in the near harbor area are not validated by measurements, and must be taken with some care. However, the *relative* change in the flow- and wave environment is predicted as accurate as it can be with today’s numerical tools.

From the analysis that the only change will be a slight increase in the wave attack (up to 10-15 cm) in the middle of Nimmo´s pier, which has an elevated coastline. Therefore no mitigation measures are needed.

6 SEDIMENTATION AND EROSION IN THE HARBOR AREA INCLUDING THE ACCESS CHANNELS:

6.1 SCOPE:

The scope is to evaluate whether the change in the hydrodynamic environment due to the proposed extension will cause additional erosion or sedimentation problems along the coast and in the near harbour area.

6.2 PROBLEM FORMULATION:

The sediment is moved around in the area due to current (fluvial outflow from Corrib River, Tidal current and wind induced current). The further presence of wind waves contribute to the sediment motion. With the changed flow and wave pattern due to the proposed extension, the sediment pattern changes accordingly. This change will lead to a shift in the erosion/deposition pattern. This may lead to additional erosion at the shoreline or changed sedimentation rates in the dredged channel(s).

6.3 ASSESSMENT:

The assessment is described in section 8.4.2, /1/, and in sections 4.1 and 4.2, /2/, pp.26-50. The assessment is done by applying the same 2D numerical Hydrodynamic tool as used in the flood risk assessment, see section 2.3.2 above. This hydrodynamic tool is coupled to a sediment transport module, SISPHYE, which is capable of calculating local sediment transport rates as well as local bed level changes (morphology).

6.3.1 Available field data:

A: Sediment properties

- ***River Corrib:***

No bed samples are presented from the Corrib River. A number of concentration measurements of suspended sediment (actually wash load) are shown in figures 4.2.3 and 4.2.5/2/p. 48-49. This data was collected by EPA in the period 2010-2013. P. 45 in /2/ states that the sediment is silt (finer than 0.06 mm).

- ***The Bay:***

The transport of sediment depends strongly on sediment properties and sediment availability. The sediment includes silt and finer sediment as well as coarser fractions like fine and coarse sand. Table 8.4.2 p 8-45 /1/ lists the sediment size distribution at the bed surface around the proposed Harbor site. Most samples are taken in the Bay.

In Ch. 6, Soil /1/ some information on surface sediment properties like information of thickness of surface layers can be obtained, but no grain size distribution curves relevant to sediment transport evaluations are given.

The variation in sediment size is large. In most of the samples listed in table 8.4.2, the sediment is sand with a mean grain diameter about 0.2 mm. This value has also been applied in the morphological calculations described later in this section.

B. Sediment transport and Morphology

- ***River Corrib:***

The annual supply of *fluvial* sediment transported by the Corrib River flow is estimated based on the EPA-data to be between 5-10.000 tons of sediment (p.47 /2/). Of this 50% or more is estimated not to settle in the harbour area because of its small particle diameter (p. 47 /2/). In the future, this value will most likely drop, because the sewage outlet in Corrib River has been closed after the construction of the Mutton Island plant, /1/, Ch. 6, p.6-14.

Some of the sediment is usually transported in higher concentrations very near or on the bed (bed load). This is the coarser fractions which will not be measured by the EPA data. The bed is rocky, and not covered by sand because coarse sediment is trapped in the lakes (Corrib Lough) 8-10 kilometers upstream, so the bed load, if any , will be on a starving bed. A trap has been installed to catch bed load in Sep. 2014, but no sediment was trapped (p.47 /2/). However the flow in September 2014 was historical low and this measurement is therefore not representative.

- ***The dredged channel:***

Detailed bathymetric surveys around the existing navigation channel from 2012 and 2014 exist, so difference-maps indicating erosion/deposition patterns can be elaborated, figure 4.1.1 /2/ p.28. From this plot it is seen that the channel is self-cleaning in the dock area, while sedimentation occurs outside in the bay. Some information on sediment transport can be obtained from the dredging data of the existing access channel, which traps around 9000 cbm. annually, p. 27 /2/, corresponding to 5 cm deposition per year.

- ***The Bay:***

In the bay, wind waves play an important role in stirring up bed sediment from the seabed, which is then transported by the current. This causes a longshore littoral drift directed eastwards. No estimate of the quantity of sediment is given in /1/ or /2/. Some field information on the longshore drift should be possible to obtain from observations of bathymetry-changes W of the Mutton Island causeway from 2002/03, when the Mutton Island causeway were constructed. This causeway may expect to trap most of the Eastward drift of sediment.

6.3.2 Numerical simulations:

6.3.2.1 Bed shear plots:

A number of hydrodynamic plots regarding the bed shear stress during the existing and after the proposed extension are presented in /1/, figs. 8.4.16 to8.4.39. Since the mobility of sediment depends on this number, these plots give a good picture of where deposition/erosion is most likely to occur. Because of the large variation in grain sizes, table 8.4.1 is included. From this table you can get an idea about whether different fractions will move or not. The plots do not include impact of wind waves, but includes different values of River Corrib flow at Neap and Spring tide – (reduce font size to 11pt - same as the rest of the text).

6.3.2.2 Morphological calculations:

/2/ section 4 complements the findings in /1/ by inclusion of real morphological simulations, where changes in sediment transport capacity leads to deposition/erosion patterns: if you have a spatial *increase* in the bed shear stress you get *erosion* because you transport more out of the area than inward and vice versa. This leads to a number of cases presented in figures 4.1.2-4.1.17). The transport in the bay is dominated by waves (longshore littoral drift), which also has been modelled using the “SISYPHE” modeling system. The numerical simulations comprise:

- *15 days spring-neap-spring simulations with medium (figs 4.1.2-9) and high (figs 4.1.10-17 River Corrib flow with different grain properties (grain sizes), namely silt and fine sand. No wind waves are present.*
- *Wind waves formed by 30 m/sec wind from S and SW plus Atlantic swells combined with medium River Corrib flow and spring tide, Figs. 4.18-21. The calculations are based on an assumed mean sand size equal 0.12 mm (fine sand).*

6.4 MAIN RESULTS:

6.4.1 Tidal current and River Corrib flow

Section 8.4.2.6 /1/ (p. 8-18) is a discussion of changes in the sedimentation patterns, partly due to the creation of a dredged access channel, and further also to the change in the flow direction of the Corrib in-and outflow:

The proposed development changes the current, mainly by concentrating the outward directed flow from the Corrib River, where the western Marina Breakwater acts as a guiding wall. This implies larger flow velocities along this breakwater and in the new navigation channel to the Corrib Docks (p. 8-18 /1/), which is beneficial for the flushing ability of the new navigation channel.

This is confirmed by the shear stress plots, from which it can be concluded the shear stress (or erodibility) will increase in the proposed dredged channel to Galway docks as compared to the present. The shear stress is also evaluated to increase in the approach channel past the head of the proposed southern breakwater (due to flow contracting).

Due to spatial variations in the bed shear stress, it turns out from fig. 4.1.17 p. 37 /2/ that the proposed dredged channel to the Galway Docks may not be self-cleaning all along the Marina breakwater, but actually some sedimentation may occur at the proposed Marina entrance at large flow rates in river Corrib (272 cbm/sec), The deposition rates here exceeds 3 mm/day at these high flow rates.

It is also concluded that the area in front of the commercial harbor will experience nearly no morphological changes, so here will be no sedimentation problems. This is most likely due to the sheltering effect of the proposed extension to the outflowing sediment from Corrib River.

6.4.2 Impact of wind waves on morphology:

The storm waves generate a longshore sediment transport eastwards, which easily can be observed in the figures 4.1.18-21, where the Mutton Island Causeway in the model is seen to trap a significant amount of sand, so the seabed will raise west of the causeway.

The erosion/deposition activity in the vicinity of the harbour area is small now and also for the proposed case compared to more exposed locations like West of Mutton Island and East of Hare and Rabbit Island. At these locations the coast is exposed to erosion now and also after the proposed extension. The main reason for this low sediment activity by waves in the near harbor area is the sheltering impact of the Mutton Island causeway.

Regarding *shoreline erosion* this is discussed in /2/ p. 38: the proposed extension will reduce erosion (as well as deposition) east of the Corrib entrance because of the proposed extensions sheltering effects to incoming waves from W and SW.

Further away, the impact from the proposed development on sediment transport will be insignificant

6.5 COMMENTS:

The longshore littoral drift: At the oral hearing in January 2015, the applicants stated that no field observations indicated that sediment was trapped westwards of the causeway except for some algae. Some sand and silt would be expected to deposit westwards if the longshore drift was significant. In a figure like 8.4.2 in /1/, some trapping actually seems to occur. The bed elevation here is based on the bathymetric survey, very briefly described in /1/ section 8.2. With an estimated increase in bed elevation of 2 m over an area of 1km cross-shore and 300 m alongshore, this could indicate that 600,000 cbm (cubic meters) are trapped during the last 12 years, corresponding to an estimate of the longshore drift of sediment around 50,000 cbm. annually.

This picture does not differ much from some of the bathymetric pictures like that in fig. 4.1.18 /2/, and a crude comparison between model and bathymetric changes could have been done to test the sediment transport module. If the predictions by the module is not confirmed, one reason for this could be that loose sediment not is available in the bed (starving bed). This is an important feature, the implications of which have not been assessed in the information submitted.

The model has been run for different storm wave directions. The different scenarios should be combined to illustrate what typically would happen in the bay on an annual basis regarding movement of sediment.

The dredged channel: as mentioned above, the proposed dredged channel to the Galway Docks may not be self-cleaning all along the Marina breakwater: some sedimentation may occur at the proposed Marina entrance at large flow rates in river. This might lead to increased infill of sediment into the proposed Marina basin. It has not been discussed in the EIS whether this could be an issue.

The sedimentation pattern is depicted in figures 4.1.20-21, where the scale is so small so you hardly van observe what is predicted in the access channel. This part of the figures should be enlarged so they become more like figures 4.1.2-4.1.5.

6.6 MITIGATION:

It is concluded in /1/ that no mitigation is needed regarding the sediment transport. The only question which could be raised is whether the entrance of the proposed Marina harbor should be designed so as to avoid potential sedimentation problems in the Marina.

6.7 CONCLUSION:

The changes in the sediment pattern and the associated erosion-deposition pattern have been properly investigated using numerical modelling, the only weak point being the verification of the sediment transport module.

Regarding the sediment influx to the near harbor area from Corrib River, this estimate is based on field measurements, and is properly (and slightly conservatively) investigated.

Regarding the flow modelling, this is assessed applying the same tool as used for the flood risk assessment.

Regarding the sediment transport in the bay, the right met-ocean impact has been selected, assessing the most severe impact. It is concluded that the proposed extension is beneficial for the flushing capacity of the new channel to the existing port as well as protecting the nearby shorelines by sheltering against wave attacks. Further away, the sediment transport is so weak, so future sedimentation of the navigation channel and turning circle is nearly negligible (some sedimentation may be caused by propeller wash. This is not investigated, but is most likely insignificant).

7 SEDIMENT FROM CAPITAL DREDGING DURING THE CONSTRUCTION PHASE

7.1 PROBLEM FORMULATION

Total Capital dredging of 1.815 million cbm is required in relation to the proposed extension, /5/ p.6-17. This dredging will comprise of stiff material (rocky) as well as in soft sediment like silt and sand. The dredging operations must not harm the nearby aquatic environment, and for this reasons a maximum concentration of released material must not exceed the limit of 6000 mg/l, /1/ p. 8-44.

7.2 DREDGING OPERATION

The dredging will be done by Pontoon Mounted Backhoe Long arm Excavator (stiff material) and a Trailer Suction Hopper dredger (soft material). Usually a suction hopper will cause largest concentrations of suspended matter release to the surrounding environment during dredging as compared to the excavation device. This is because in the operation of the suction hopper, the dredged material is mixed with water to get the sediment into the hopper. While the sediment is supposed to settle, the mixing water is returned to the sea by overspill from the chamber. Finer fractions will overspill together with the water, which usually results in large concentrations in the release of suspended sediment. (Typically 4-6% of the dredged material is released). In the EIS /1/ p. 8-44, the spill during dredging is assumed smaller: with a dredging rate of 40 l/s, equivalent to 150 cbm/hour, the release (spill) of sediment is assumed to be 875 kg/hour, corresponding to 0.6 cbm/hour. This corresponds to a spill equal only 0.4%. The reason for this very small release of dredged material is, that the mixture of sediment and water dredged by the suction hopper to get the new channel to the old port immediately will be pumped further from the Hopper though pipelines into lagoons 1 and 2, both being located in the proposed extension (/2/ p. 42). These lagoons are lined by geotextile and constitute a part of the proposed development. For this reason the main contribution to the release of sediment originates from the Excavator operations.

7.3 ASSESSMENT OF SPILL BEHAVIOR:

In /1/ section 8.4.2.8, the dispersion of the released sediment is studied by a numerical model.

The spill is transported as a plume with the tidal flow and further diffused by local turbulence (convection-diffusion). At the same time, the spill will move towards the bed with its settling velocity. This implies that coarser sediment (i.e. fine sand) will settle near the dredger because it settles quite fast. Finer sediment (medium silt) settles slower and is therefore transported further away with the tidal current.

The process of dispersion of the released spill is modeled by TELEMAC3D, applying the worst case scenario that dredging occurs throughout the whole tidal cycle (un-mitigated), p. 42 /2/. A number of dredging locations for the sediment plume simulations have been selected as shown in fig.8.4.41, and the results are shown in figs. 8.4.42-57. The simulations cover different grain sizes (fine and coarse silt), and the flow environment has been chosen to be Spring tide combined with Corrib Summer low flow. Wind waves are not included in the analysis, but the dredger will not operate during such conditions.

In /1/ the dredging rate has been put equal 3500 cbm /day. The EIS addendum complements this with a larger dredging rate of 17000 cbm/day, /S1/section 3.3.3.

7.4 MAIN RESULTS:

Fig. 4.1.22 in /2/ depicts the calculated concentrations of spill, where the spill is taken to be in the silt fraction, while in reality approximately 50% is coarser, namely fine sand. The coarser the sediment being released is, the closer the dispersed spill will settle near to the dredger, and therefore a significant part here will be re-dredged during the operation. Therefore the model predictions are on the safe side (conservative). Nevertheless, the impact is quite low: the thickness of the layer of deposited spill can be obtained from figure 4.1.22 (by combining the figure with the text on the opposite page) and do not reach more than a few mm during 12 months of operation, cf. the text p. 42/2/ .

Fig. 8.4.43 illustrates that fine sediment can be brought into the Lough Atalia during flood tide flow during dredging operations at the locations of the inner (northern) part of the new channel to the old port adjacent to the Marina breakwater.

Capital dredging further away at the turning circle and the commercial and fishing pier berth has a much localized impact due to the lower flow velocities at this location. The deposition rates here are small as compared to natural deposition rates.

7.5 COMMENTS:

- None.

7.6 MITIGATION:

The spill is transported with the water-flow, so during flood some sediment will be brought into Lough Atalia, as seen on e.g. fig. 4.1.22. By only allowing dredging during ebb flow, virtually no spill will be transported to Lough Atalia (best practice).

The requirement that the released sediment concentration is being kept below 6000 mg/l is ensured by monitoring: Turbidity meters will be installed at dredge sites to monitor the dredging operations, /1/ Ch. 6 p.17.

7.7 CONCLUSION:

The capital dredging will not cause significant release of spill, mainly because the sediment slurry during suction immediately is pumped further through pipelines to lagoons, where the sides are covered by geotextile.

The release of sediment which inevitably will occur during dredging operations are investigated by using a numerical model, which illustrate that some silt may be brought even to Lough Atalia during raising tide. This can be mitigated only by performing dredging operations in the new access channel to the old port during ebb flow.

8 MAINTENANCE DREDGING

Dredging of the existing access channel to Galway Port is dredged every 10th year. In the future, the sedimentation is expected to be smaller, cf. section 3.3.1 B in this review. Therefore the proposed extension will not cause increased impact from maintenance dredging. The new access channel to the commercial port and the turning circle will be exposed to less sedimentation by current because the larger water depth.

8.1 COMMENTS:

While wind waves are not an issue during dredging operations, wind waves can contribute to faster sedimentation during storms, thus requiring larger maintenance dredging. The morphological calculations presented in /2/ like fig. 4.1.21 could suggest that maintenance dredging of the access channel to the proposed commercial port must be done a little more frequent than stated in the EIS /1/ p. 8-60.

9 SALINITY

9.1 PROBLEM FORMULATION

Near the Corrib entrance, the salty water in the bay is mixed with the freshwater supplied from River Corrib: The salinity in the Galway Bay is lowered by influx of freshwater from the Corrib River, and parts of the Lough Atalia and Renmore is supplied with salty water during incoming tide.

Because of the density difference between the heavier salty water and the lighter freshwater, this results in a complex three-dimensional picture of salt and freshwater flow, where the freshwater due to buoyancy will be dominantly at the surface, while the salty water will be concentrated at the bed, causing vertical variations in density (vertical gradients). Also horizontal variations are present in density where you have the transition from salty to fresh water (horizontal gradients). The size of these gradients depends on several parameters such as tidal regime and influx of fresh water, so the vertical gradients can be small (well mixed) or large. The photo in /1/ 8.4.65/66 shows a sharp front in the bay between the salty and fresh water, so in this case the flow obviously is stratified with large gradients. /S4/ also mentions stratification during parts of the tidal cycle close to Corrib River entrance.

Because the proposed extension modifies the flow pattern, the salinity variations in the inner Galway Bay and Lough Atalia will be modified as well.

9.2 FIELD DATA AVAILABLE

The present salinity conditions are evaluated based on earlier investigations (ranging from 1977-2011) complemented by new comprehensive surveys carried out in the Bay in 2009 and in the harbour and Lough Italia in 2011/2014. The Field surveys are mainly measurements of the surface salinity, but those from Lough Atalia include salinity variations over the depth

9.2.1 Lough Atalia and Renmore Lagoon:

Lough Atalia is a 39 ha tidal Lough, which is connected to the sea via a 430 m long tidal channel, c.f. p.3 and fig. 1 p 5 in /3/. During the initial phases of the incoming spring tide, fresh water from Corrib River is pushed into the Lough, while more salty water is brought to the Lough later in the spring tide. The lough is partly emptied during ebb. During a single spring tide, the lough is nearly flushed, /3/ p.4.

Salinity measurements were carried out in January and March 2013 at 21 different sampling locations in 2012 and at 10 other locations in 2013/14, depicted in figs. 5 and 6, p. 10/3/ and in Figure 8.4.58-62 /1/.

The measurements were repeated on a number of different days during several months to cover different tidal ranges. At the two sampling locations nearest the connecting tidal channel, the salinity variations were continuously monitored for several weeks. Here the vertical variations were measured as well.

/1/ p. 8-70 further reports survey work done in Aug 2011, and again Sep. 2011 and May 2012. In the two latter surveys, the salinity in Renmore Lagoon (connected to Atalia Lough through a culvert and a drainage channel) has also been measured, fig. 8.4.61 p. 8-72 /1/.

A complete list of the surveys is presented in /4/, p.11-12.

9.2.2 The inner Galway Bay:

Here, a number of salinity measurements are available. Some of those are measurements from a vessel April 2009, p. 8-70 /1/, and these also include vertical salinity profiles. Furthermore historical data 1984-1989 is presented for a number of stations, shown in figure 8.4.58 p. 8-70 /1/.

9.3 ASSESSMENT

The impact of the extension is analyzed partly by using numerical models, which is calibrated applying some of the field measurements described in the former subsection.

Stratified flow is highly 3D as described in section 6.1, and this is difficult to model, especially close to the salt water wedge, where the gradients are large. The flow is modelled applying a 3D-flow model (TELEMAC-3D and five different simulations with different water discharge in Corrib River ranging from low flow (9.1 cbm/sec) up to flood flow (272 cbm/sec) .

Calibration: The surveys described above are mainly applied to calibrate the model by adjusting bed roughness, diffusion coefficient and turbulent viscosity to fit the measured salinity profiles as best as possible, /4/ section 3.6. Afterwards, the detailed predictions like variations in salinity with depth and time are compared with the measurements. Generally, in Lough Atalia the model slightly under predicts the salinity at low salinities, and over predicts it at high values, cf. figs 30, 31 and 37 /3/ (it is impossible to distinguish between the different red colors used in the figures)

9.4 MAIN RESULTS

In the bay, the modeling shows that the salinity *east* of the proposed extension will increase in the order of 2-6 ppt (parts per thousand), because the bay water here will be less mixed with the fresh water from River Corrib. This is because the proposed extension will act as a barrier between the outflowing freshwater and the salty water east of the proposed extension. *West* of the proposed extension, the salinity similarly will decrease slightly, /1/ p. 8-84. South of Nimmo´s pier, the decrease is predicted to be 1.5-2 ppt.

In Lough Italia, the mean salinity will be slightly reduced (by 1.3 ppt in average). This decrease is closely linked to the decrease in salinity in the inner Galway Bay west of the proposed extension.

Renmore Lough has only inflow from Lough Italia at water levels in Atalia higher than 1.77 m O.D., p 8-107, /1/ because of the bathymetry of the connecting channel. This is, other than rainwater, the only source of inflow, so the salinity variations strongly depend on the salinity in Lough Atalia at water levels above 1.77 m O.D. (Spring tide). In Renmore Lough, the water similarly becomes slightly fresher: the mean salinity will decrease by around 1.2 ppm.

9.5 COMMENTS

Hydrodynamic modeling:

Information on the grid sizes used in the model is given in the separate report /4/, where figure 20 shows that the depth is divided into 5 sub- layers. This is not enough layers to describe a sharp interface as the wedge, so the model can most likely not describe measurements from 1984 regarding the position of the saltwater/freshwater front (fig. 8.4.65/66). This problem is treated in the model by applying a mixing length model with damping functions,/4/ p. 15, which is one way to overcome this problem. In the inner Loughs, the flow is partly mixed with a much smaller vertical gradient, and here the applied model is appropriate as indicated on p 21 in the report /4/: the model "is considered fit for the purpose of predicting *relative* differences in salinity between the existing and proposed cases".

9.6 MITIGATION

No mitigation is proposed. The largest relative impact will be east of the proposed extension. The only way to reduce this predicted change in salinity is by creating a connection in the bay water between E and W of the proposed extension as close to the Corrib entrance as possible. Even such a costly connection will only impact the salinity changes slightly and is most likely not feasible.

In Lough Atalia, the salinity already during existing conditions is reduced to nearly zero at large fluvial discharges in the river Corrib, so mitigation here should not be necessary.

9.7 CONCLUSION

The proposed extension will impact on the salinity distribution by increasing it east of the extension and similarly decreasing it westwards of the proposed extension. The numerical model suggests quite moderate changes of order a few ppt. While the model not is capable of describing very sharp interfaces between salty and fresh water, it is an adequate tool to apply to describe *relative* changes in salinity away from these sharp interfaces, which constitute most of the area which could be affected.

The model results depicted in figs 8.4.76-90 looks all quite reasonable from a qualitative point of view, with a distinct rise in salinity East of the proposed extension after its construction (because the Corrib River Flow is prevented from being mixed with the Bay water here), and a moderate decrease in salinity in the bay between the Mutton Island causeway and the proposed extension, where the Corrib River flow becomes more concentrated. In Lough Atalia, the salinity is predicted to decrease slightly because the water entering this Lough now becomes slightly fresher.

The numerical assessment is qualitatively physical consistent, and the number of runs is appropriate to investigate the impact at different hydrodynamic environments.

10 EFFLUENT DISPERSION STUDIES

10.1 PROBLEM FORMULATION

The effluent released from Mutton Island Outfall and the proposed Galway East Outfall will be transported around in the bay by the tidal- and wind induced current. The problem to be considered is whether the proposed extension will lead to a larger concentration on the near shore areas and the Corrib River entrance, the latter due to a funnel effect.

10.2 FIELD DATA AVAILABLE

None.

10.3 ASSESSMENT

The dispersion has been modeled using numerical model tools. /1/ pp. 8-108-134 presents the findings of the application of a 2D (depth-averaged) numerical model (TELEMAC2D). The use of such a model requires that the flow velocity as well as the outfall is uniformly distributed over the depth. This latter is a reasonable assumption if the outfall has same density as the salty bay water. Because the outfall discharges at Mutton Island are well mixed with the surrounding water through a 10 port diffuser manifold, /2/ p. 110, the density and thereby the buoyancy effects are minor. Further, the outfall is diluted when becoming mixed with the surrounding bay water to about 1:30 according to /S1/ 3.5.5.

Impact of wind: The dispersion predictions become slightly larger if treated by a 3D-model including surface shear from wind blowing above the water: The wind transports the surface layer much further away than corresponding to the depth averaged velocity. This 3D flow investigation is done in /2/, where the analysis by the TELEMAC2D is complemented with a number of runs with the TELEMAC-3D model to take account for the vertical variation in flow velocities due to wind effects. The outfall discharge was discharged as a surface layer in the model to illustrate the impact of a surface plume, /2/ p. 111.

The dispersion has been studied based on the mean Spring and Neap tidal cycles with a medium River Corrib low flow of 82 cbm/sec. The wind field is the parameter to be varied in strength from calm conditions up to 15 m/sec, and in direction from SW to S. This will cover the most exposed cases of effluent transported towards the Corrib River entrance.

The effluent has been considered as a conservative tracer (no chemical reactions or die-out with the surrounding salty water) for dissolved matters like ammonia, nitrates etc. These runs are presented in figs. 4.8.1-4.8.42, /2/.

Faecal Coliforms has been studied as well in 4.8.43-4.8.48 /2/ by also applying the 3D flow description. In this numerical study the die-off has been included.

10.3.1 Galway East outfall:

/2/ also includes a study of the proposed Galway East Outfall, located 2.4 km SE of the Mutton Island outfall. Here wind from SE, S and SW have been imposed in the model, and shown in figs. 4.8.49-4.8.66.

10.4 MAIN RESULTS

The 2D modeling indicates that the only impact by the proposed extension is caused by the general change in the flow pattern between the proposed extension and the Mutton Island causeway.

If the wind-effect is included in the 3D modeling, it is seen that the proposed extension will cause an increase in the concentration west of the marina breakwater, with an associated decrease at the Ballyloughaun Beach.

10.4.1 Conservative tracers:

Under calm wind conditions a slight increase is predicted by the model at the Corrib entrance, Lough Atalia and along Renmore shoreline area. The increase however is very small: below 0.1% of the effluent concentration just north of the outfall.

Under stronger wind conditions the plume path especially for wind coming from S (fig. 4.8.23) is pushed further northwards into Lough Atalia. However, the relative change before and after the proposed extension is predicted to be less than 0.1%.

10.4.2 Facial Coliforms:

This will die-off while being transported by the flow, the die-off rate being conservatively estimated (by around a factor of two, p.135 /2/.) The simulations predicts a very slight increase due to the proposed extension as compared to existing conditions in the bacteriological concentration at the Corrib River entrance (from 451 to 490 cfu/100ml under SSW 15 m/s wind conditions, and an increase from 130 to 227 cfu/100 ml during calm wind conditions).

10.4.3 Galway east outfall:

The impact of the proposed extension on the plume concentrations from the proposed Galway East is greatest for SE winds. Actually the proposed extension will improve the conditions W and N of the Corrib River entrance (and thereby also protect Lough Atalia), while E of the proposed extension, an increase up to 0.08% is found in the vicinity of the commercial port and Hare Island (p. 150, /2/).

10.5 COMMENTS

The dispersion study is significantly improved in /2/ as compared with /1/ in including wind effects properly.

Most of the predicted changes are easily understandable, but figure 4.5.53 is unusual in predicting a localized impact from the proposed extension at Galway east outfall location during SW wind. This has no implications, but suggests an uncertainty in the model predictions.

10.6 MITIGATION

No mitigation has been recommended, because the calculated changes are so small, so they are considered not needed to be mitigated.

10.7 CONCLUSION

The dispersion study is a high-standard numerical study, in which the met-ocean impact has been properly selected to cover the worst-case-scenario.

11 MITIGATION ISSUES

The impact and mitigation issues regarding the marine environment are summarized in /1/, section 8.5 p. 8-213, table 8.5.1.

Regarding flooding, changes in wave impact, sediment transport and salinity it is concluded that the short- and long term impacts are minor, and no mitigation is needed.

Regarding dredging, the capital dredging impact is short termed and can be minimized by following best practice, i.e. by avoiding dredging along the proposed Marina Breakwater during incoming tidal flow. The maintenance dredging is long termed (short term serial), and here the impact can be minimalized similarly.

Regarding release of sewage, the impact is long termed and is suggested to be minimized by following best practice.

Comments:

The reviewer agrees with the main conclusions in the EIS regarding the mitigation measures. The only measure to reduce salinity changes would be to make a passage for the water to flow in a channel or culvert through the extension close to the present shore. The usage of this is probably minor or negligible, but could be considered nonetheless.