Memo

From	**Richard Measures and Jochen Bind**
To	Karen Wilson, Environment Southland
CC	Hugh Robertson and Nicki Atkinson, Department of Conservation
Date	20 November 2024
Subject	Validation of Waituna Lagoon inundation and land drainage modelling

Background

Te Rūnanga o Awarua, Department of Conservation Te Papa Atawhai (DoC) and Environment Southland (ES) are in the process of applying for consent to conduct periodic openings of Waituna Lagoon. The assessment of effects included with their application relies in part on modelling conducted by NIWA and described in the 2016 report Waituna Lagoon level impacts on land drainage and inundation[1].

The 2016 NIWA modelling study mapped the inundated area and "drainage affected area" for a range of lagoon levels. The modelling included backwater effect in the creeks entering the lagoon for two different river flows, a median river flow (exceeded 50% of the time) and a 90th percentile high-flow (exceeded 10% of the time). "Drainage affected area" was intended to represent the area of land that would experience reduced drainage effectiveness, resulting in increased waterlogging during and after rainfall. The modelling study assumed that land within either 1.0 or 2.0 metres elevation of the adjacent lagoon water level would be "drainage affected" (both 1.0 and 2.0 metre thresholds were mapped separately).

To assess the accuracy of the results presented in the 2016 NIWA modelling report, ES have contracted NIWA to compare the model results against image and video files showing observed inundation in September and October 2024. This imagery includes a prolonged period of lagoon levels exceeding 2.3 m until the lagoon was opened on 25 September 2024 and levels dropped.

Methodology

ES supplied NIWA with UAV (Unmanned Aerial Vehicle, i.e., drone) imagery and videos for three dates. Imagery was available at one or more of those dates for the mouths of each of the three creeks entering Waituna Lagoon: Carran Creek, Moffat Creek and Waituna Creek.

The dates of images/videos for each site are listed in Table 1 below.

[1] Walsh, J. M., Measures, R. J., Bind, J., Haddadchi, A. (2016). Waituna Lagoon level impacts on land drainage and inundation: Investigation stages 1 and 2. *NIWA Client Report CHC2016-010 prepared for Department of Conservation*.

Table 1: Dates (and corresponding lagoon level and creek flow) of image and video files captured at each location

Date	11 Sep 2024	23 Sep 2024	24 Oct 2024
Lagoon level	2.48	2.59	0.7
Creek flow	High (~90th percentile)	Medium (~50th percentile)	Very high (>>90th percentile)
Site	**Imagery available for site/date (Y/N)**		
Carran Creek (mouth)	N	Y	Y
Moffat Creek (mouth)	Y	N	Y
Waituna Creek (Marshall Road north of Hanson Road)	N	N	Y

We reviewed the supplied material and picked out the most useful image and video files for each date/site combination to compare with the model results from the 2016 report. Lagoon water level and flow data on the dates on image/video capture were supplied by Environment Southland.

When assessing the model results, we also used LiDAR-derived land elevation data to quantify the relative elevation of different areas of observed inundation. We used LiDAR data from 2012[2] (as used in the original modelling) as well as the recently released Southland LiDAR 1 m DEM[3]. Comparing the two LiDAR datasets had the additional purpose of validating the elevation data used in the original modelling. All elevations given in this report relate to the Bluff 1955 vertical datum unless otherwise stated. Vertical datums are discussed further in the discussion section of this memo.

Results

The following section contains general observations relating to conditions during the 2024 data capture as well as commented, direct visual comparisons of the results from the 2015–17 models with image data captured in September/October 2024. Following this results section we have included a separate section with discussion and conclusions regarding the overall performance and limitations of the modelling.

Carran Creek

Images and videos were collected along Carran Creek from a UAV above the bridge at Waghorn Road on 23 September 2024 between 11:20 and 11:40 NZST, as well as on 24 October 2024 around 10:30 NZST. Lagoon levels recorded at Waghorn Road on 23 September 2024 between 11:00 NZST and 12:00 NZST were recorded to vary between 2.586 m and 2.590 m. Water levels around 10:30 NZST on 24 October were 0.700 m.

We selected four images as being most useful for validation:

- A georeferenced orthophoto created from vertical aerial photos taken of the area around the Waghorn Road bridge and water level recorder on 23 September 2024 (Figure 1).
- An oblique aerial image extracted from video looking upstream from above the Waghorn Road area showing Carran Creek and its true right bank on 23 September 2024 (Figure 2A).

[2] Collected between 20-22 March 2012 by NZ Aerial Mapping for ES

[3] Captured for Environment Southland by Aerial Surveys Ltd between 15 December 2020 to 30 January 2024, https://data.linz.govt.nz/layer/113172-southland-lidar-1m-dem-2020-2024/.

- An oblique image extracted from video looking upstream over the true left bank of Carran Creek on 23 September 2024 (Figure 3A).
- An oblique image extracted from video looking upstream over the true left (eastern) bank of Carran Creek on 24 October 2024 (Figure 4).

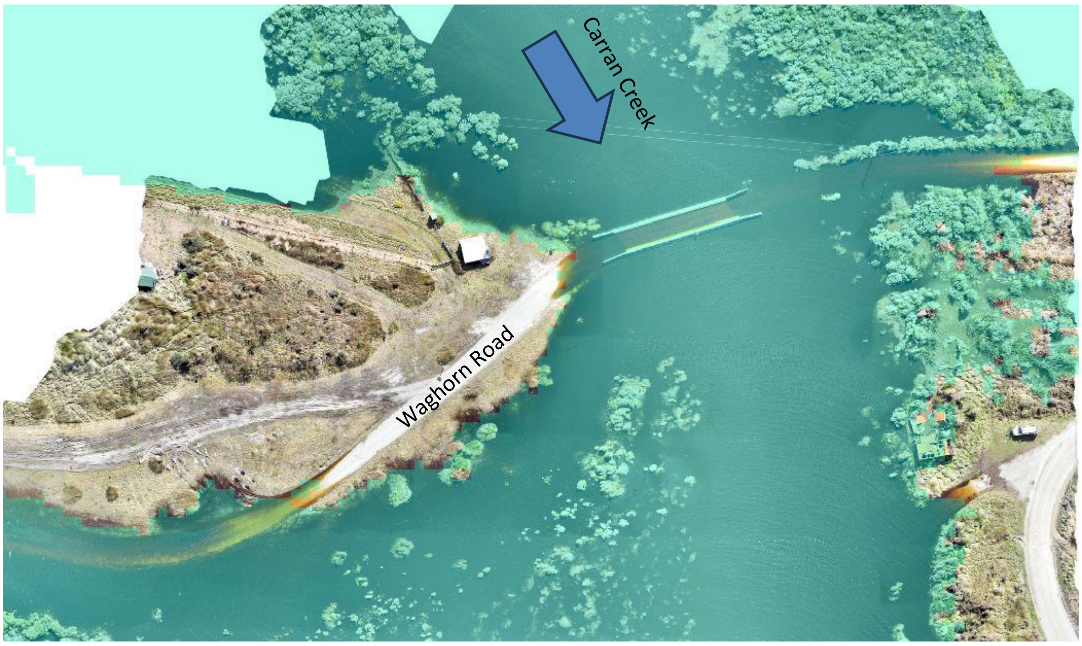

Figure 1: Carran Creek orthophoto, 23 September 2024 (level at Waghorn Road water level recorder ~2.59 m), overlaid with model results for inundation at 2.5 m lagoon level (light blue pixelated overlay).

Figure 1 shows a very close match between a modelled lagoon level of 2.5 m and the observed inundation extent shown in the orthophoto generated from images taken on 23 September 2024. Note that the water level during image capture was roughly 9 cm higher than the highest lagoon level that was investigated in the modelling study (2.5 m). Note that river flow and channel vegetation has no effect on modelled inundation for this location when lagoon levels are 2.5 m (it does have an effect further upstream on Carran Creek).

Figure 2A shows the right bank upstream of Waghorn Road bridge on 23 September 2024. The corresponding model result for a lagoon level of 2.5 m is shown in Figure 2B. Within wetland areas emergent vegetation obscures the inundation extent, but three distinct areas of inundation along the farmed edges of the wetland (A–C) can be identified in both aerial image and modelled inundation. There is good agreement between the modelled and observed inundation extent.

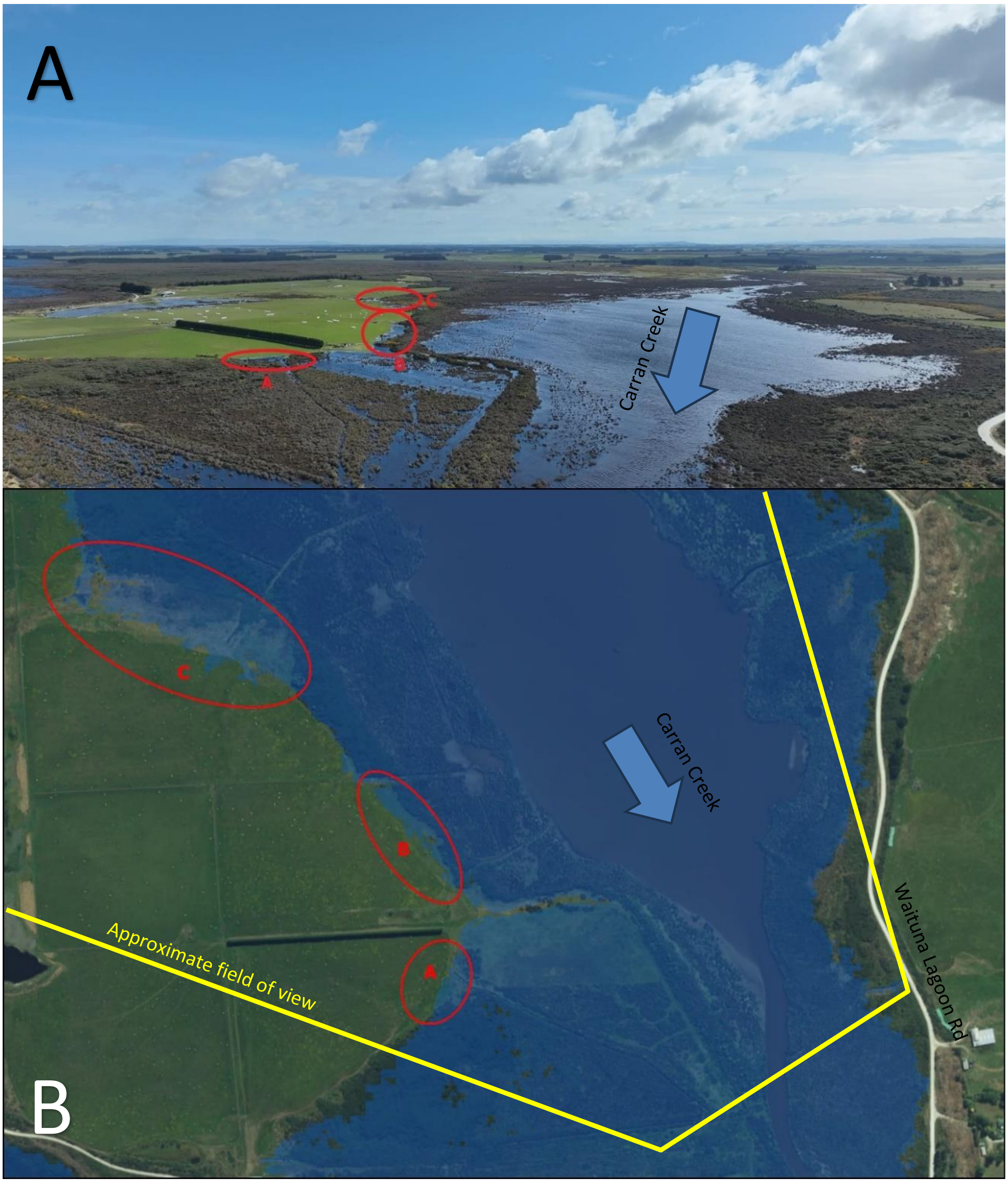

Figure 2: Panel A: Carran Creek right bank above Waghorn Road bridge on 23 September 2024 when lagoon level was 2.59 m; Panel B: model results for lagoon level at 2.5 m (modelled inundation extent is the same for all simulated river flows and channel vegetation conditions at this location when lagoon levels are 2.5 m).

Figure 3 shows the lower part of Carran Creek on the left bank of the creek. We understand that the flooded wetland area in the distance (marked E) has been intentionally flooded via modifications to the small stream/drain and did not exist at the time of the original modelling. The areas marked D and F are separate from this wetland and are inundated in the imagery from 23 September 2024. Bathtub modelling at lagoon levels of 2.5 m do not indicate this area to be inundated. LiDAR data of ground elevations suggests that the water levels in area D are approximately 3.6 m, over 1 m higher than the lagoon level at the time of the imagery, and in area F are approximately 5.2 m, over 2.5 m higher than lagoon levels. The model results show area D as “drainage affected” under the 2 m threshold, but not under the 1 m threshold. Area F is not shown as drainage affected.

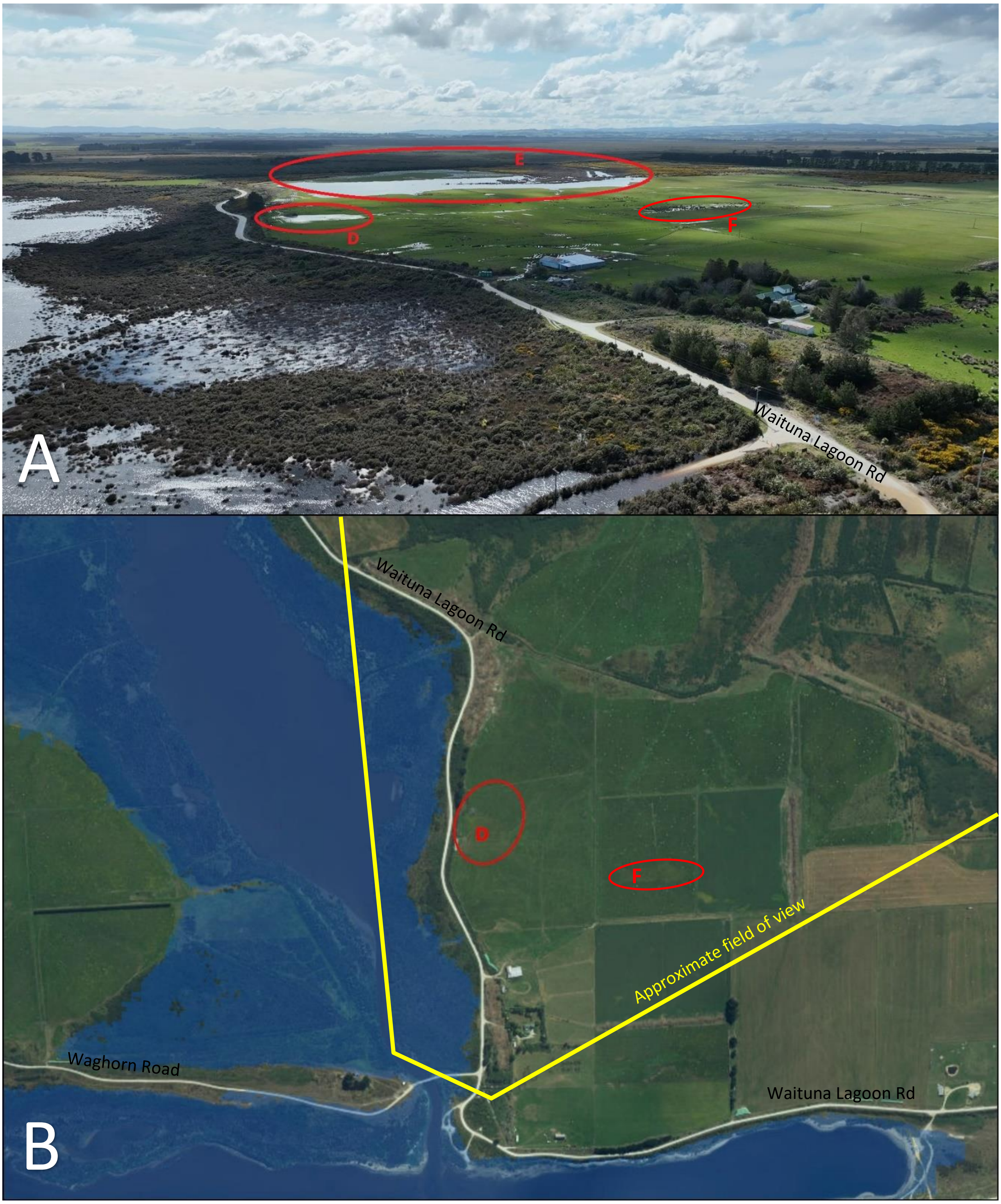

Figure 3: Panel A: Looking upstream along Carran Creek left bank from UAV above Waghorn Road bridge on 23 September 2024 when lagoon levels were 2.59 m; Panel B: model results for lagoon level at 2.5 m (modelled inundation extent is the same for all simulated river flows and channel vegetation conditions at this location when lagoon levels are 2.5 m).

The aerial footage in Figure 4 shows more extensive submerged areas on the left bank of the creek despite the lagoon levels being (much) lower on 24 October 2024 (approximately 0.725 m, almost 2 m lower than in Figure 3A). It is likely that the extensive patches of surface flooding shown in this image (patches D, F, and other additional areas of surface flooding not visible on 23 September 2024, Figure 3) are the result of recent heavy rainfall. Data from the closest ES rain gauge (Waituna at Lawson Road) record 15.5 mm of rain on 23 October and a further 24.0 mm of rain prior to the image shown in Figure 4 being taken at 10:30 NZST. Discharge of Carran Creek at Waituna Lagoon Road was gauged at 11:30 NZST on 24 October 2024 as 3.21 m^3/s.

Figure 4: Carran Creek left bank looking upstream from above Waghorn Road bridge on 24 October 2024 when the lagoon was open and lagoon levels were approximately 0.7 m (Creek just outside left side of image).

Moffat Creek

Images and videos were collected from UAV from the end of Moffat Road on 11 September 2024 around 12:00 NZST as well as on 24 October 2024 around 9:40 NZST and then again around 11:30 NZST. Lagoon levels on 11 September 2024 at 12:00 NZST were 2.480 m. Water levels recorded at Waghorn Road on 24 October were 0.664 m and 0.722 m, respectively. Discharge of Moffat Creek was gauged at Moffat Road at 10:50 NZST on 24 October 2024 as 1.878 m^3/s.

We selected three images as being most useful for validation:

- A wide-angle view of Moffat Creek and farmland either side just upstream of its mouth (taken from above the end of Moffat Rd on 11 September 2024 (Figure 5A).
- A zoomed-in view of farmland on the true left bank of Moffat Creek from above end of Moffat Rd on 11 September 2024 (Figure 5B). This image was selected to provide more detail of inundated areas.
- A wide-angle view of Moffat Creek and farmland either side just upstream of its mouth on 24 October 2024 (Figure 6)

Two main areas of inundated land are visible in Figure 5A, labelled A and B. Patch B shows water ponding in a topographical low spot about 100 m west of Moffat Road. This area is not connected directly to any water body like the river or the lagoon and might be ponded rainwater. Patch B is not shown as inundated in any of the models. Land elevations in this area are about 5.6–5.7 m.

Patch A is shown more clearly in Figure 5B. Inundation of land is visible on both sides of the creek, with a ‘tongue’ of water extending behind the fishing huts on the eastern side of the mouth and an area of river-parallel inundation on the western side. Also visible in Figure 5B is Patch C along the edge of the farmland adjacent to the wetland vegetation. The land elevation in Patch C (from LiDAR) ranges between 2.55 and about 2.7 m. The angle of the imagery obscures the view to see whether Patch C is connected directly to the lagoon/creek, but judging by the ground elevations, it appears more likely to be a local depression filled with rain runoff.

Figure 5C shows the results of the modelling for a 2.5 m lagoon level at the 90th percentile high flow (0.514 m^3/s) and “vegetated channel” scenario. This model result is for a very similar lagoon level to the time of the survey, with a similar, but slightly lower flow (Carran Creek flow[4] at the time of survey was 0.80 m^3/s). The modelling results in Figure 5C correspond very well to the observed inundation around the mouth. However, the imagery from 11 September shows more inundation further upstream on the creek, particularly on the left bank (Patch D) where there is no inundation in the model. Inspection of land elevations in this area shows values between 2.6 and 2.75 m in the 2020–24 DEM, which are in line with the modelled water levels of around 2.75 m in this part of the creek. However, the 2012 DEM shows higher land elevations, which is why the modelling did not predict any inundation. Closer inspection reveals a pond surrounded by slightly raised land in 2012 (the pond surface elevation was captured in the LiDAR). The pond has now been infilled (i.e., the pond is not visible in the 2020–24 DEM or recent aerial imagery) resulting in a slight overall lowering of the area on the pond margins. As well as the labelled patches of inundation (A to D) there are several other small wet areas visible in paddocks which are not shown in the model results. These areas have higher elevation than the lagoon and are likely local areas of ponding.

[4] There is no flow recorder on Carran Creek but ES calculates a synthetic flow record based on calibrated relationships with other local flow recorders.

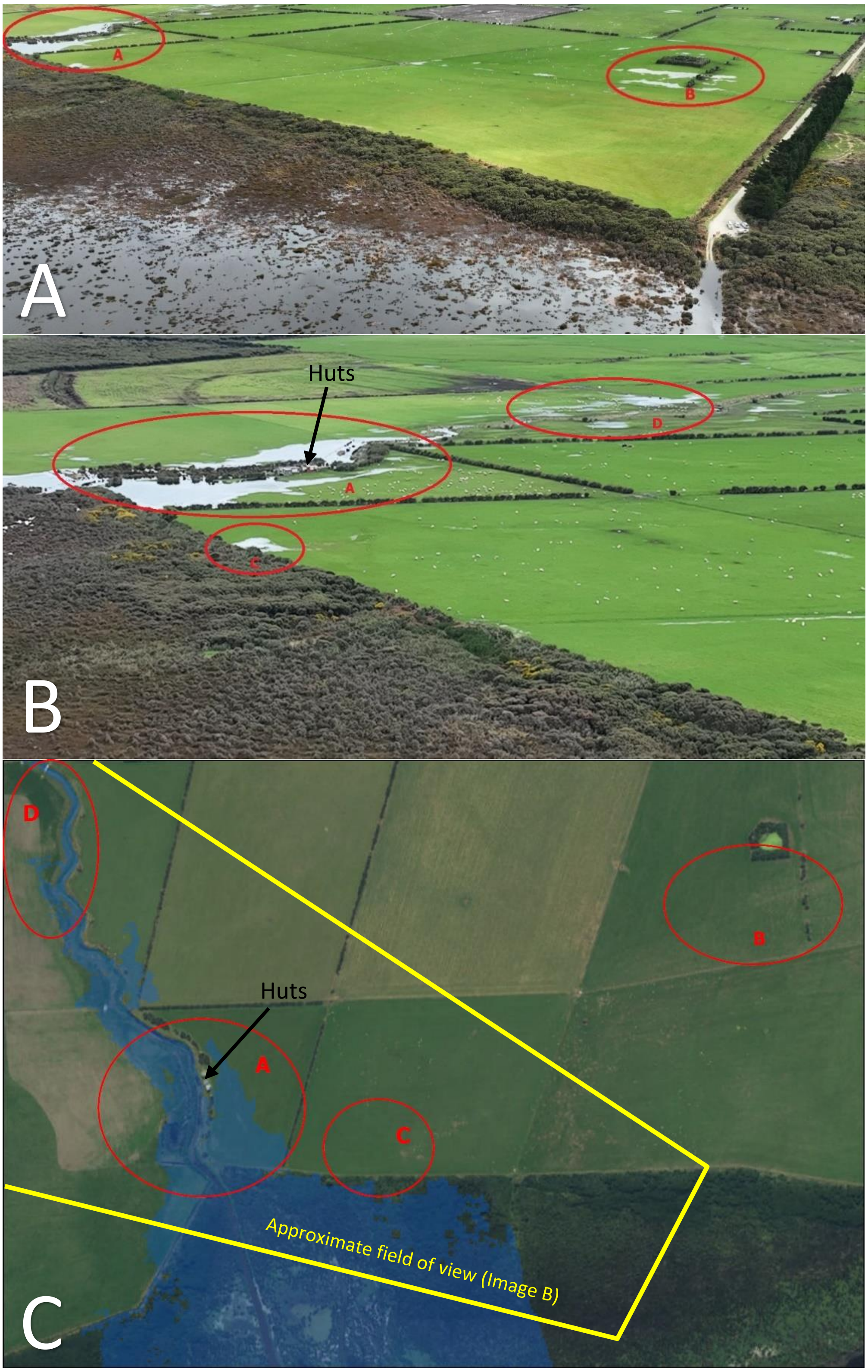

Figure 5: **Panel A and B: Lower Moffat Creek on 11 September 2024; Panel C: model results for Q90 and "vegetated channel" scenario in Moffat Creek and lagoon level at 2.5 m.**

Figure 6 shows the area around the Moffat Creek mouth on 24 October 2024, when lagoon levels were much lower (approximately 0.7 m) and much of the previously inundated land was exposed. However, muddy areas that had been submerged can be seen behind the fishing huts and there is a shallow, water-filled channel visible in the paddock (patch E) that was not inundated in the imagery from 11 September 2024. The water in this depression/channel is likely rain-runoff from the heavy rain which preceded the survey on 11 September. Patch C is also clearly still inundated, which supports the theory of a local depression, filled with run-off water.

Figure 6: Moffat Creek on 24 October 2024. Lagoon open, lagoon water level approximately 0.7 m, creek flow very high (greater than 90th percentile).

Waituna Creek

Images and videos were collected from UAV from above the bend in Marshall Road north of Hanson Road on 25 October 2024 around 11:00 NZST. Two images were selected, Figures 7 and 8 show the view upstream and downstream, respectively. Many low-lying areas (particularly the depressions of old meander channels) are filled with water.

Unfortunately, the area captured in the images and video is mostly beyond the reach covered by 2016 modelling study and there are no images which can be used to validate the area around the mouth of Waituna Creek. Figure 7 shows the area immediately upstream of the model inflow boundary while Figure 8 shows the area around the inflow boundary for the model. However, they are still relevant to discuss as they show inundation, but the modelling study showed that the backwater effect of lagoon levels does not extend this far up stream (Figure 9). Land elevations in the inundated areas shown in the imagery (all greater than 6 m elevation) are much higher than the lagoon level, even prior to the opening on 25 September.

Although lagoon levels were low during the time that the UAV imagery was captured on 24 October (around 0.7 m), river flows were gauged by ES at 14.33 m^3/s, which is much higher than the highest modelled discharge (4.15 m^3/s, representing the 90^{th} percentile flow). Additionally, there had been significant rainfall over the two days prior to UAV image capture. The inundated areas shown in the UAV imagery are very likely to be the result of either river flooding or rainfall ponding (or a combination) and are unlikely to have been influenced by lagoon levels.

Figure 7: Waituna Creek on 24 October 2024, looking upstream along Marshall Road (right in image). Lagoon open, lagoon water level approximately 0.7 m, creek flow very high (greater than 90^{th} percentile). The upstream end of the Waituna Creek Model is below the UAV, just outside the frame at the lower margin of the image.

Figure 8: Waituna Creek on 24 October 2024, looking downstream from Marshall Road, North of intersection with Hanson Road. Lagoon open, lagoon water level approximately 0.7 m, creek flow very high (greater than 90th percentile). The upstream end of the Waituna Creek Model coincides with the right margin of the aerial photo. The model shows no inundation in this reach.

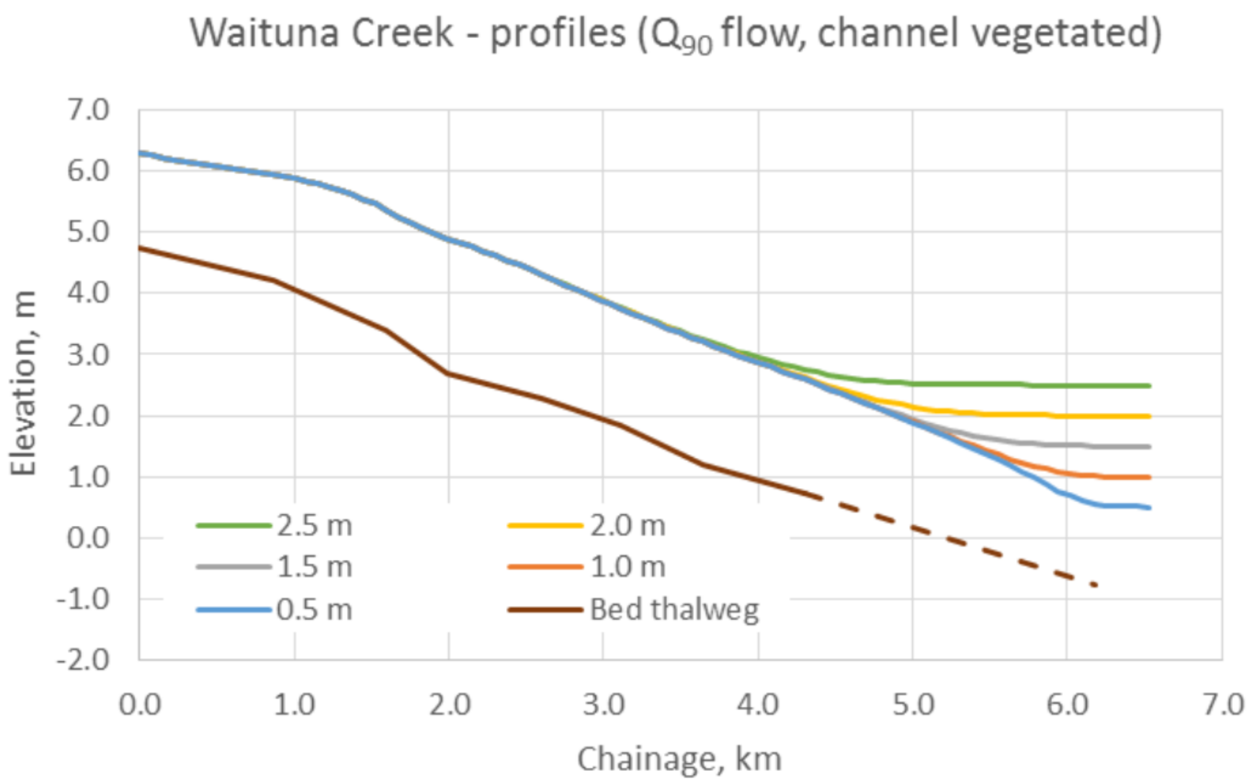

Figure 9: Modelled Waituna Creek backwater profiles (reproduced from Figure 4-8 of Walsh et al. 2016). Figures 7 and 8 show the area around chainage 0.0 km in the plot above.

Discussion

Observed vs modelled inundation

Imagery data collected in September 2024 corresponds to a lagoon level of approximately 2.5 m, which corresponds with the lagoon opening threshold proposed in the consent application and was one of the lagoon levels modelled in the 2016 study. Areas of ponded water around the lagoon and creek margins, which are visible in the UAV imagery, are consistent with predictions from the 2016 modelling. The strongest evidence for this comes from the georeferenced ortho-image of the Waghorn Road bridge area of Carran Creek (Figure 1) where inundation extent from a 2.59 m water level, almost exactly matches modelled inundation for 2.50 m (i.e., the closest modelled water level).

There are some areas which are shown as submerged in the UAV images which are not shown as inundated in the modelling results. These areas of disagreement tend to be isolated patches of water, not directly connected to the lagoon or creeks (e.g., Carran Creek patch D in Figure 3 and Moffat Creek patches B and C in Figure 5). Inspection of the land elevation in these areas reveals that they are higher than the lagoon water levels recorded at the time of the imagery, in some cases only slightly higher, but in other cases more than 3 m higher than lagoon levels (e.g., Moffat Creek patch B in Figure 5). It is notable that during September and October the Waituna area (and much of Southland) experienced extreme rainfall. The closest raingauge (Waituna at Lawson Road) recorded 146% of normal rainfall over this period.

In addition to mapping areas of inundation for different lagoon levels, the 2016 report also mapped “drainage affected areas” which could experience poor land drainage during periods of elevated lagoon levels. Most of the isolated areas of water visible in the UAV images are within these drainage affected areas, although the most elevated patch (Moffat Creek patch B in Figure 5) is outside the model predictions of drainage affected area. It is not possible to say definitively whether drainage of this patch would be any different at a lower lagoon level, however, given that the land elevation of this patch is approximately 3 m above the lagoon level it seems unlikely that a lagoon level of say 0.5 m lower would significantly alter the drainage effectiveness.

Imagery collected on 24 October was taken when the lagoon was open and had low water levels (approximately 0.7 m), during high river flows following a period of heavy rain. This imagery was of limited use for direct validation of the modelling, but it did highlight that significant areas of ponding inundation can occur during heavy rain and high streamflows in the absence of any affects from lagoon level.

Ground elevations and vertical datums

While comparing water levels and ground elevations, great care has to be taken to define the vertical reference for each measurement. This is done by stating levels/elevations in reference to a vertical datum. The DEM used for modelling was referenced to Bluff 1955 vertical datum and is consistent with the Waghorn Road lagoon water level recorder. No specific datum information is included in the consent application (elevations are referenced as relative to “MSL”, i.e., mean-sea-level, which is somewhat ambiguous), but we assume the levels referred to in the consent are consistent with the Waghorn Road recorder, and hence are in the Bluff 1955 vertical datum.

The 2020–2024 LiDAR DEM is referenced to New Zealand Vertical Datum 2016 (NZVD2016). The difference between Bluff 1955 and NZVD2016 in this area is around 25 cm, so we applied the geoid separation surface to the recent DEM to compare the ground elevations between the two DEMs. We created a DEM-of-Difference (DoD) between the two DEMs to check for systematic offsets or errors in the old DEM. However, no systematic error was apparent. Most differences were within +/- 5 cm between the two DEMs. Exceptions to this were generally confined to the wetland areas where the 2012 DEM was generally lower. This can be explained by the growth of vegetation over the decade between the two LiDAR captures. While the DEM aims to represent ground elevations, the vegetation cover in the wetland areas is so dense, that extracting ground points from LiDAR is difficult. Other exceptions were observed on farmed land, where it is assumed that differences in groundcover (grass) height account for the differences. This is supported by the fact that these anomalies generally follow field boundaries.

Conclusions

Overall, the 2016 modelling accurately reproduces observed areas of inundation at a 2.5 m lagoon level with 90th percentile river flows, indicating the results are broadly appropriate for use in the consent application.

There are ponding areas visible in the UAV imagery which are elevated above the lagoon. The ground elevations in these ponding areas are generally within 1 to 2 m of the lagoon water surface elevation, and their drainage may be influenced by lagoon level. Applying the 2 m threshold for calculating “drainage affected area” is a more conservative approach than the 1 m threshold (both were mapped in the original study).

Imagery from 24 October highlights that inundation and ponding is possible following high rainfall and river flows, irrespective of lagoon level.

Finally, we suggest that the consent application define a specific vertical datum for the lagoon opening thresholds to assure clarity and consistency in any observations and modelling moving forward, especially considering ongoing sea level rise.

Acknowledgements

UAV imagery and lagoon level and flow data were supplied by Michael McDonald and Chris Jenkins at Environment Southland.

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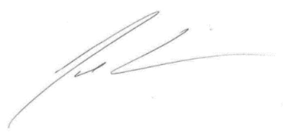
NIWA Project: ENS25504

Revision	Description	Date
Version 1.0	Final version sent to client	20 November 2024

Quality Assurance Statement		
	Reviewed by:	Jason Alexander
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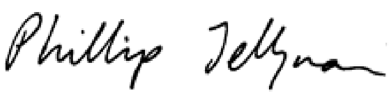	Approved for release by:	Phillip Jellyman