

Volume and Shoreline Changes along Pinellas County Beaches during Tropical Storm Debby

**Ping Wang and Tiffany M. Roberts
Coastal Research Laboratory
University of South Florida
July 24, 2012**

Introduction

This report discusses the volume and shoreline changes along three barrier islands, Sand Key, Treasure Island, and Long Key, at Pinellas County beaches induced by Tropical Storm Debby. Tropical Storm Debby impacted the Pinellas County beaches for several days from June 24th to the 26th and generated high waves and elevated water level for approximately three days. Beach and nearshore profiles were surveyed two weeks (June 2 – June 10, 2012) before and approximately one week after (June 28 – July 3, 2012) the impact of Tropical Storm Debby. This report quantifies the sand volume changes along the three barrier islands. Location changes of two contour levels representing the dune-line and high tide line were also examined.

Methodology

A total of 145 beach profiles were surveyed approximately every 300 m (1000 ft) at R-monuments established by the State of Florida. The survey lines extend to roughly -3 m (10 ft) NAVD88, or to the short-term closure depth in this area. This closure depth seems to hold during the occurrence of large waves induced by Tropical Storm Debby, with a negligible amount of sand transported seaward of -3 m (10 ft) NAVD88. Horizontal and vertical controls were established using Real-Time Kinematic (RTK) Global Positioning System (GPS). Level-and-transit survey procedures were followed using an electronic total survey station and a 4-m (13 ft) survey rod. The survey was conducted using NAD83 State Plane (Florida West 0902) coordinate system in meters, referenced to NAVD88 (~ 8.2 cm (0.27 ft) above mean sea level in the study area).

Beach volume and contour analysis were conducted using the software RMAP (Regional Morphology Analysis Package), developed by the U.S. Army Corps of Engineers. Erosion or deposition in the dune field, the dry beach, above the nearshore region, and across the entire

profile was calculated. The dune field is defined here as the portion of the beach above 1.3 m (4.3 ft) NAVD88 (the elevation of typical beach fill along this coast). The dry beach is defined here as the portion of the beach between 1.3 m (4.3 ft) and 0.3 m (1.0 ft) NAVD88 (approximately Mean High Tide, MHT). The nearshore portion of the beach is determined based on the characteristics of individual profile changes (discussed in the following). The closure depth is also determined based on the changes measured at each individual profile, discussed in the following. At some profiles, especially those near the tidal inlets, the survey did not extend to closure depth due to the extensive distance of shallow water offshore associated with ebb tidal shoals.

In the following, the beach volume and contour-line (i.e., dune line and high tide line) changes are described from south to north. Based on previous research on the beach behavior, the beaches along the three barrier islands are divided into the following segments:

Long Key Barrier Island:

Pass-A-Grille Beach:	R160-R165:	nourished in 2004
Middle Long Key:	LK6-R160:	not nourished
Upham Beach:	LK1B-LK6:	nourished in 2010 with geotextile T-Groins

Treasure Island Barrier Island:

Sunset Beach:	R137-R143:	nourished in 2010
Middle Treasure Island:	R128-R137:	not nourished
Sunshine Beach:	R127-R128:	nourished in 2010

Sand Key Barrier Island:

Madeira Beach:	R116-R124:	not nourished in 2006
Redington Beach:	R107-R116:	not nourished in 2006
North Redington Beach:	R100-R107:	nourished in 2006
Indian Shores:	R89-R100:	nourished in 2006
Headland:	R82-R89:	nourished in 2006
Indian Rocks Beach:	R71-R82:	nourished in 2006
Belleair Shore:	R66-R71:	not nourished in 2006
North Sand Key:	R55 – R66:	nourished in 2006, being nourished now

General Beach Profile Changes

Considerable longshore variations of beach profile changes were measured. Patterns of beach profile change play a significant role in volume-change calculations and the interpretation of the results. This section describes general characteristics of the beach-nearshore profile changes. The goal is to provide a visual and qualitative description to help interpret the calculated volume and contour line changes. Detailed profile changes will be discussed in the following reports. All the surveyed beach-nearshore profiles are listed in the Appendix at the end of this report. It is worth noting that the profiles are listed from north to south with increasing R-monument numbers for more convenient indexing. However, the following discussions on beach changes are from south to north, aligned with the direction of Debby-induced longshore sand transport. Influenced by the track of Tropical Storm Debby, the wind and waves approached from a highly oblique southerly angle, driving a northward longshore sand transport. Beach morphology changes reflected this northward longshore transport.

In general, sand loss occurred in the dune field, on the dry beach, and in the nearshore zone, while sand gain occurred over the nearshore bar. This pattern of profile change is illustrated in Figure 1. Sand volume change associated with the dune field was calculated as the volume change above the contour line of 1.3 m (4.3 ft) NAVD88. Volume change on the dry beach was calculated as the volume change between contour levels 0.3 m (1.0 ft) and 1.3 m (4.3 ft) NAVD88. In the case of profile R75 (Figure 1), overall sand volume loss (including sand losses from the dune, the dry beach and the nearshore) was calculated as the changes landward of approximately 90 m (295 ft) distance, where mostly erosion occurred. Volume gain over the sandbar was calculated as the changes seaward of 90 m (295 ft), where mostly accumulation occurred. In the case of R75, the nearshore bar moved seaward (Figure 1). However, along a considerable number of profiles, the bar moved landward. At almost every profile, the nearshore bar gained substantial amount of sand.

R75

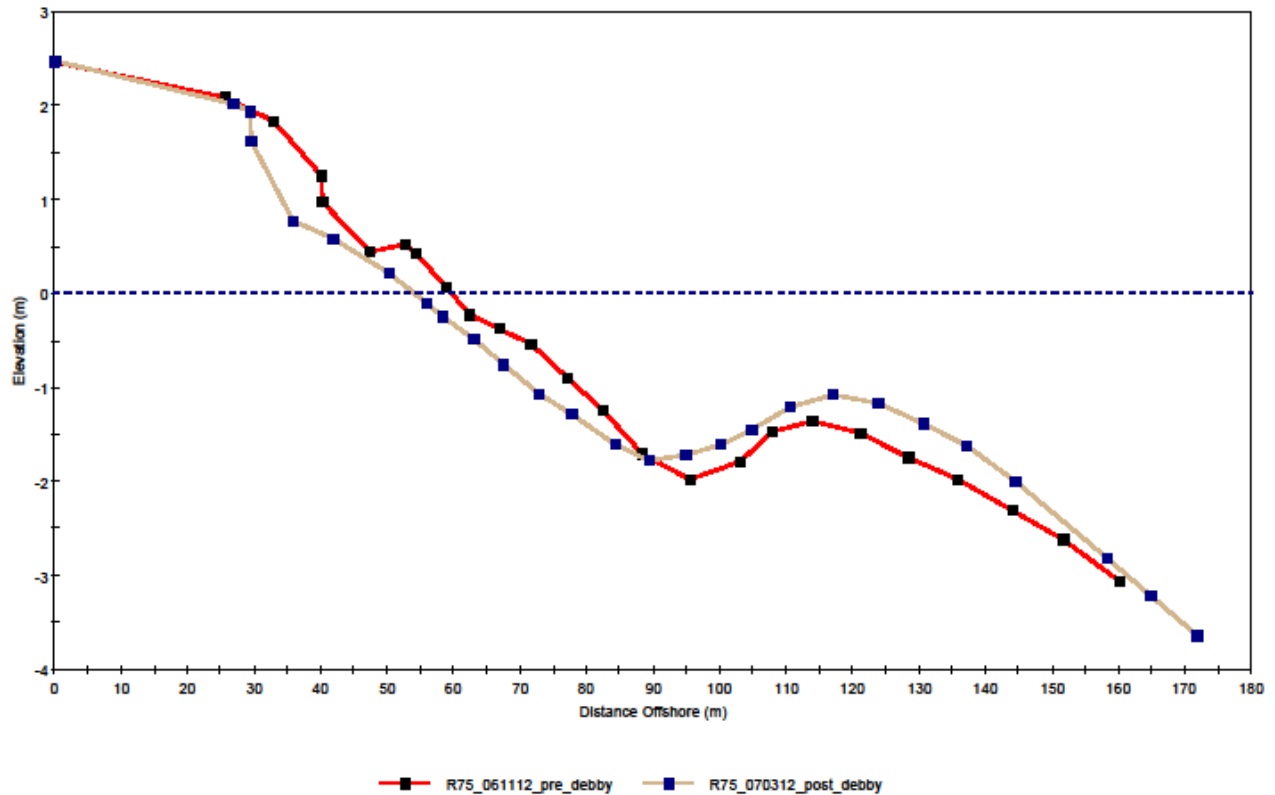


Figure 1. Example profile at R75, illustrating erosion of the dune, dry beach and nearshore area, with deposition over the nearshore bar.

Along some beach profiles, especially those with a wide pre-storm backbeach, a “storm berm” formed (Figure 2). Part of the backbeach gained sand and resulting in an overall higher elevation. Substantial erosion occurred on the dry beach and in the nearshore area. In the case of R160 (Figure 2), the nearshore bar moved onshore substantially with increased elevation of the bar crest, as compared to the pre-storm bar. In the case of profile R160 (Figure 2), the overall sand volume loss was calculated as the changes landward of approximately 100 m (328 ft), where erosion mostly occurred. It is worth noting that volume gain occurred on the dry beach landward of 100 m (328 ft) (cross-shore distance). This gain was included in the overall volume loss calculation landward of the 100 m (328 ft). Volume gain over the sand bar was calculated as the changes seaward of 100 m (328 ft), where accumulation occurred mostly.

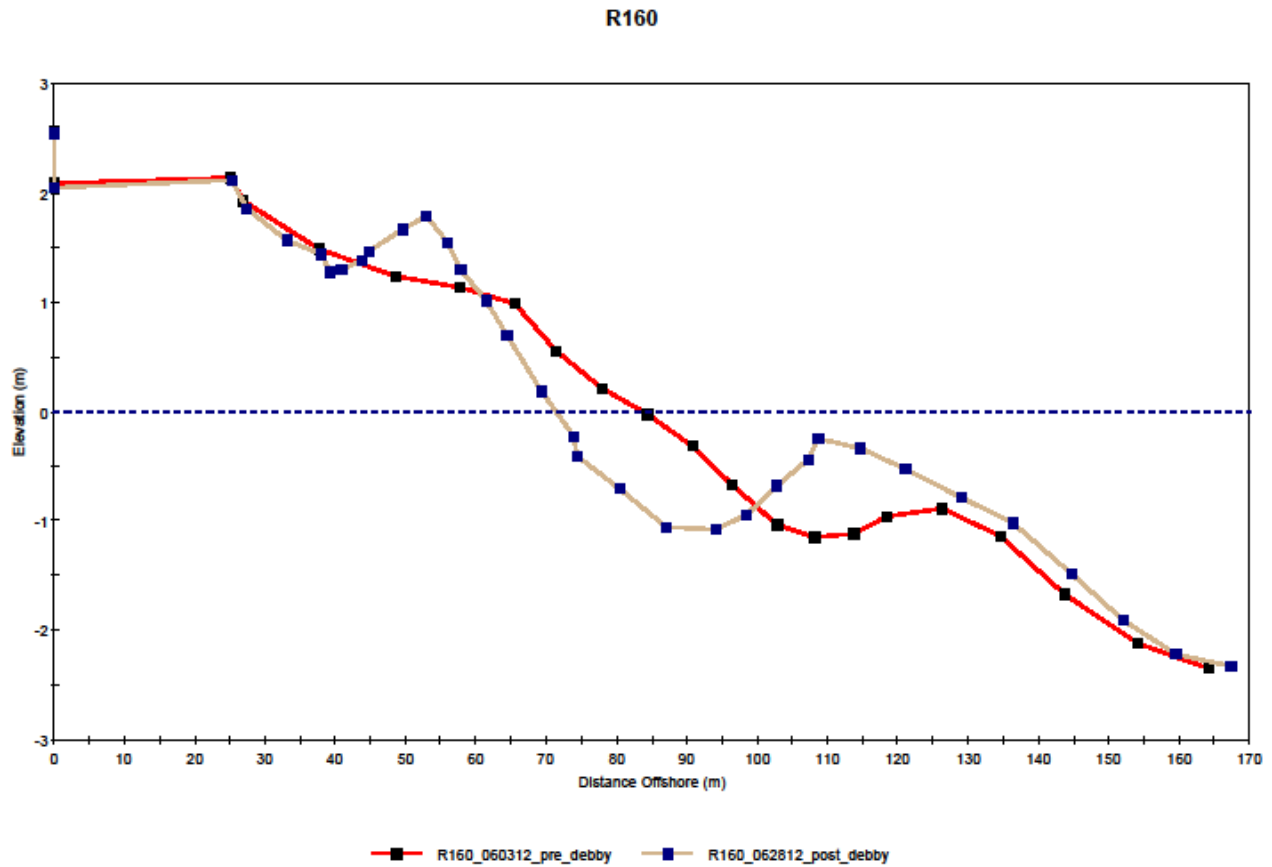


Figure 2. Example profile at R160, illustrating stable the dune, formation of a storm berm (between 40 m (130 ft) and 60 m (200 ft) cross-shore distance), and erosion of dry beach and nearshore area, with deposition over the nearshore bar.

Along sections with a narrow pre-storm beach, the dune suffered significant erosion (Figure 3), resulting in the formation of a high dune scarp. In the case of R140, a scarp of 1.2 m (3.9 ft) was formed, along with severe beach and nearshore erosion. In this case, the nearshore also gained sand and moved onshore. Overall sand volume loss was calculated as the changes landward of approximately 50 m (164 ft), where erosion occurred mostly. Volume gain over the sand bar was calculated as the changes seaward of 50 m (164 ft), where accumulation occurred mostly.

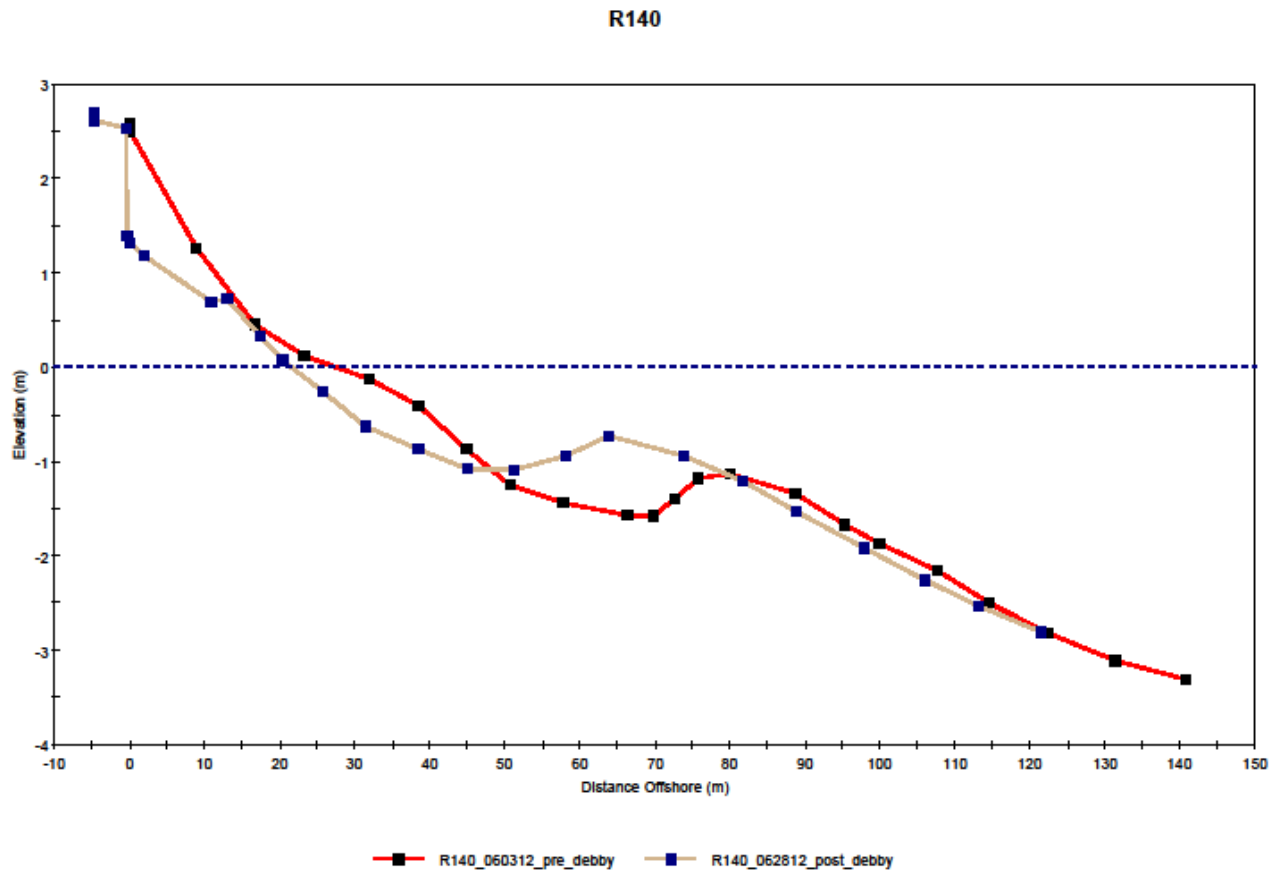


Figure 3. Example profile at R140, illustrating severe dune scarping, erosion of dry beach and nearshore area, and deposition over the nearshore bar and onshore migration of the bar.

Along sections with a narrow beach backed by a seawall, severe erosion occurred on the dry beach with scour in front of the seawall (Figure 4). In the case of R108A, severe scour occurred along the exposed seawall. It is worth noting that the seawall was exposed before the storm. However, along nearby profiles (R109 and R107), the seawall was not exposed before the storm, but became exposed and scoured due to the storm impact. In the case of R108A, the nearshore bar also gained sand and moved onshore. The division between erosion and deposition occurred at approximately 50 m (164 ft) from the benchmark.

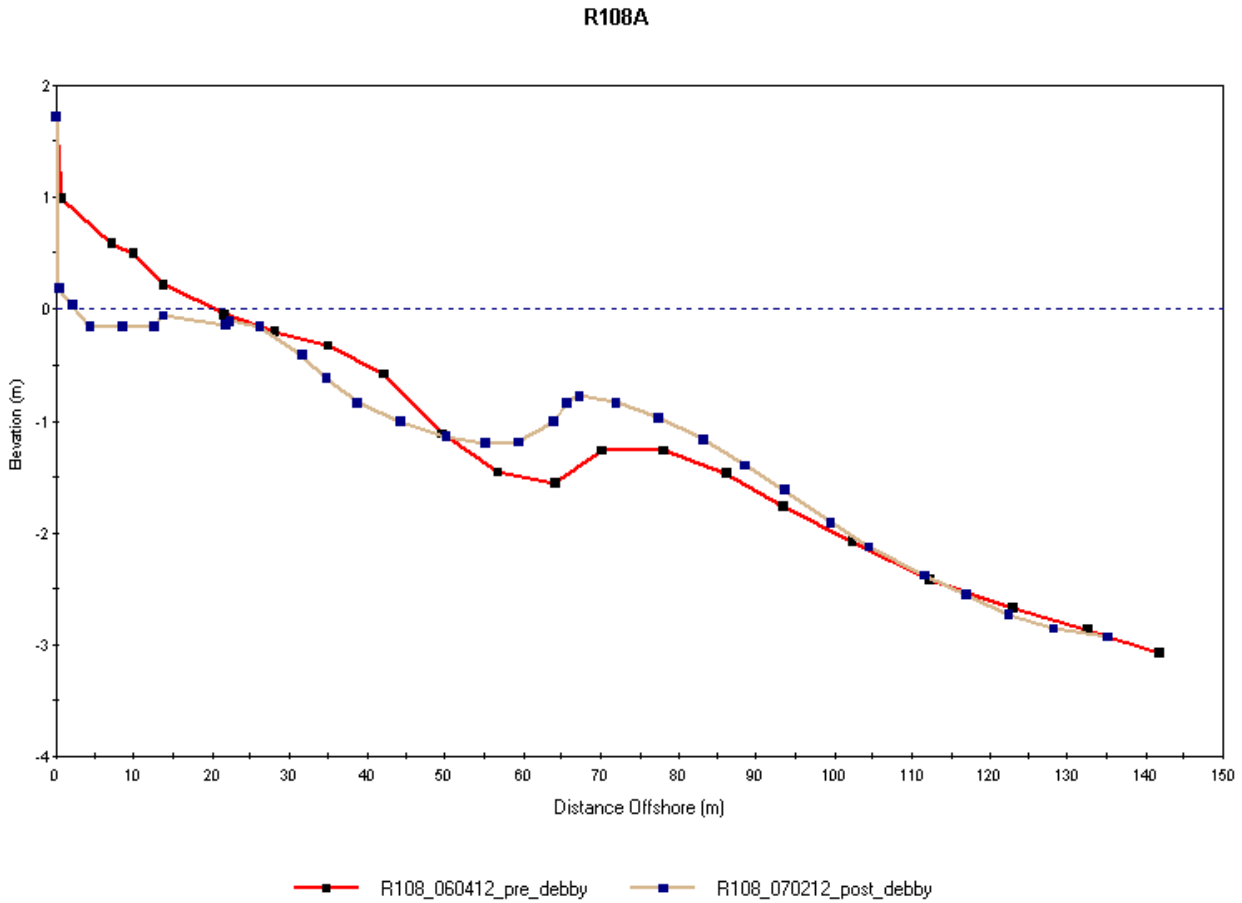


Figure 4. Example profile at R108A, illustrating severe scour in front of the seawall, erosion of the dry beach and nearshore area, and deposition over the nearshore bar.

The above response to the exposed seawall did not occur at the Belleair Shore beach. Although the seawall was in direct contact with the runup of the storm waves, no severe scour was measured in front of the seawall (Figure 5). Sand deposition occurred over most of the dry beach. Substantial erosion occurred in the nearshore zone. In the case of R66, the nearshore also gained sand and moved offshore. Overall, Belleair Shore gained sand during the storm, as discussed in the following. The division between erosion and deposition occurred at approximately 60 m (197 ft) from the benchmark.

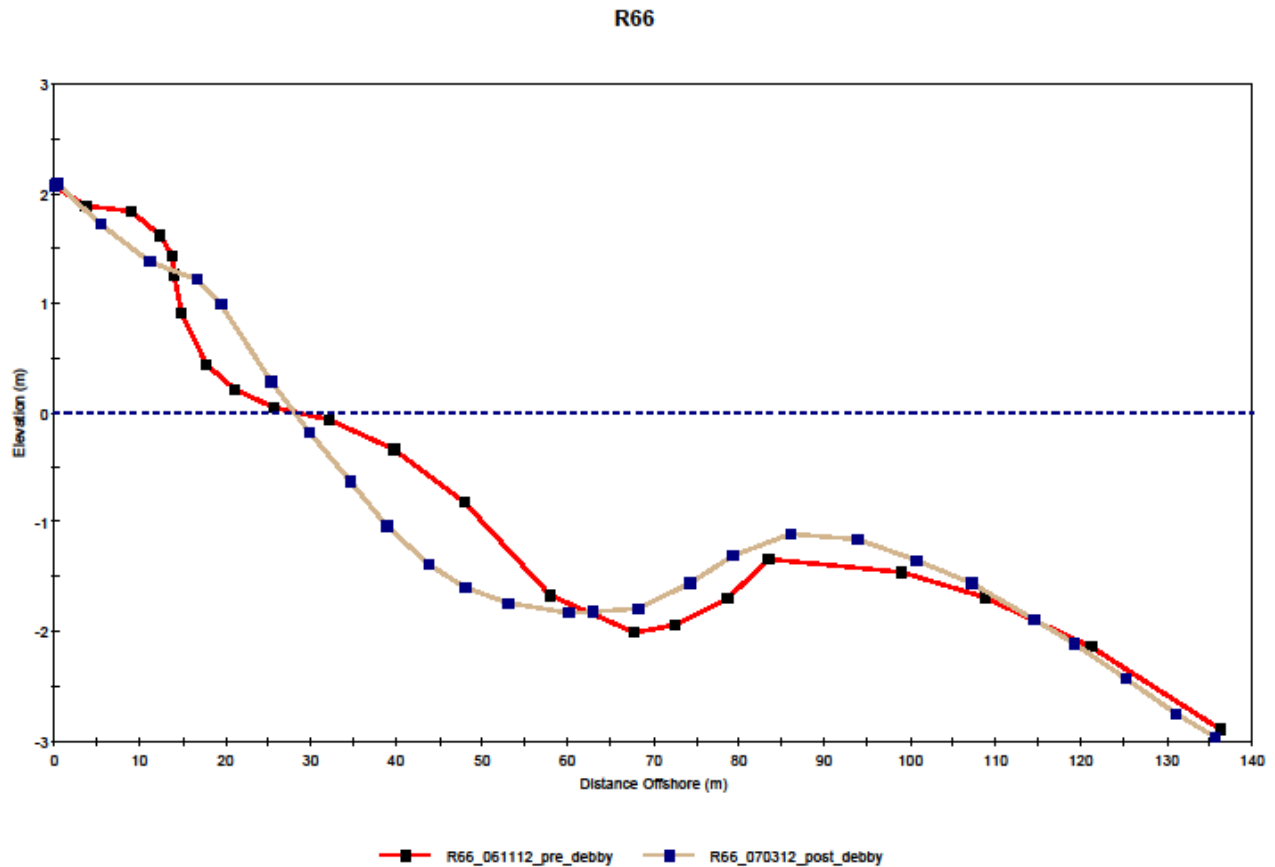


Figure 5. Example profile at R66, illustrating largely no scour in front of the seawall, deposition on the dry beach, erosion in the nearshore area, and deposition over the nearshore bar.

Volume and Contour-line Changes

Overall, the dune field lost sand due to storm-induced erosion, resulting in the wide spread development of a dune scarp and landward retreat of the dune line. It is worth noting that the “dune line” here is defined at the location of the 1.3 m (4.3 ft) NAVD88 contour line. This line coincides with the vegetated dune line at most of the profiles. However, along some sections of the beach, this contour level does not represent the vegetated dune line. This is discussed individually in the following when this case occurs. The contour line at 0.3 m (1.0 ft) NAVD88 is used to represent the seaward limit of the dry beach.

The passage of Tropical Storm Debby induced strong, sustained southerly wind for nearly three days. This southerly wind and associated southerly approaching waves induced northward longshore sand transport. Morphological evidence of the northward longshore transport can be observed at various locations. For example, sand eroded from south Long Key was transported to middle and north Long Key. This is reflected in the overall sand loss in south Long Key and overall sand gain in north Long Key, as discussed in detail in the following.

In the following, sand volume and contour-line location changes are discussed along several sections of the beach from south to north, as described above. It is worth noting that the length of individual sections is different. It should be reminded that the overall volume change is also influenced by length of the individual section of the beach.

Pass-A-Grille Beach: R160-R165

This section of the beach is approximately 5,000 ft long and was nourished in 2004. A vegetated dune field existed before the storm at all of the profiles. The southern portion of this section of the beach was fairly narrow before the storm impact. This portion suffered severe erosion. The following changes were measured along this section of the beach:

- 1) The dune field gained 1,500 cubic yards of sand. This gain is related to the development of a storm berm (with a peak elevation extending above 1.3 m (4.3 ft) NAVD88), e.g., at profile R160 (Figure 2).
- 2) On average, the dune line retreated landward 11.8 ft (3.6 m). At profile R160, due to the development of a substantial storm berm, the NAVD88 1.3 m (4.3 ft) contour line moved 39.0 ft (11.9 m) seaward. Substantial dune line retreat was measured at R163, R164, and R165, with the largest retreat of 52.8 ft (16.1 m) at R163.
- 3) The dry beach lost 22,100 cubic yards of sand.
- 4) On average, the Mean High Tide (MHT) line moved landward 25.6 ft, with substantial longshore variation ranging from 14.4 ft gain (seaward movement) at R163 to 46.2 ft retreat (landward movement) at R164. This shoreline change pattern is attributed to the seawall in front of the snack bar between these two profiles. The seawall was severely scoured.
- 5) Including erosion in the nearshore zone, this section lost a total of 36,500 cubic yards of sand.
- 6) The sandbar gained 22,900 cubic yards of sand, which is considerably less than the overall loss. Some of the sand was likely transported north and contributed to the sand gain along the beaches to the north.

Middle Long Key: LK6-R160

This section of the beach is approximately 13,300 ft long and was not nourished in 2006 or before. A vegetated dune field existed before the storm at all the profiles. This section of the beach was fairly wide before the storm impact and has been benefiting from the “feeder” Upham Beach to the north. The following changes were measured along this section of the beach:

- 1) The dune field gained 6,400 cubic yards of sand. This gain is related to the development of the storm berm (with a peak elevation extending above 1.3 m (4.3 ft) NAVD88).
- 2) The dry beach lost 31,500 cubic yards of sand.
- 3) On average, the MHT line moved landward 15.1 ft, with substantial longshore variation ranging from 14.3 ft gain at R150 to 59.7 ft retreat at R152. The reason for this large variation is not apparent.
- 4) Including the erosion in the nearshore zone, this section lost a total of 64,000 cubic yards of sand.
- 5) The sandbar gained 82,600 cubic yards of sand, slightly more than the overall loss, likely due to northward longshore sand transport from the Pass-A-Grille Beach to the south.

Upham Beach: LK1-R149: Will be surveyed July 14, 2012.

This section of the beach is approximately 2,200 ft long and was recently nourished in 2010 and is further protected by 5 experimental geotextile T-groins. A vegetated dune field existed from LK6 through LK3 before the storm. The section of the beach from LK6 to LK3 was fairly wide before the storm impact. No dune field existed from LK1B to LK 2A before the storm, with a narrow beach along this section. Upham Beach suffers from aggressive chronic erosion and serves as the feeder beach to the middle section of Long Key. The following changes were measured along this section of the beach:

- 1) The dune field gained 270 cubic yards of sand. This gain is related to the development of the storm berm (with a peak elevation extending above 1.3 m (4.3 ft) NAVD88).
- 2) The dry beach lost 5,100 cubic yards of sand.
- 3) On average, the MHT line moved landward 10.8 ft, with substantial longshore variation ranging from 6.9 ft gain at LK3 to 32.7 ft retreat at LK2. The reason for this large variation is not apparent.
- 4) Including the erosion in the nearshore zone, this section lost a total of 12,900 cubic yards of sand.
- 5) The sandbar gained 20,400 cubic yards of sand, slightly more than the overall loss, likely due to northward longshore sand transport from the Pass-A-Grille Beach to the south.

The Entire Long Key

Overall, all of Long Key suffered dune, dry beach, and nearshore erosion, especially along the Pass-A-Grille beach at the southern end, while the nearshore bar gain substantial amount of sand. Overall along the 20,400 ft studied section of Long Key, a total of 8,100 cubic yards of dune sand gain was measured. This small gain was caused by the development of the storm berm, where the peak elevation exceeded the 1.3 m (4.3 ft) NAVD88 at some locations. The dry beach lost 58,700 cubic yards of sand. Substantial erosion also occurred in the nearshore zone, extending to the trough landward of the bar at up to approximately -1.5 m (4.9 ft) NAVD88. Including the dune, dry beach, and nearshore erosion, the total sand loss along Long Key amounted to 113,400 cubic yards. Most of the sand was deposited on the nearshore bar, with a total sand volume gain of 125,900 cubic yards. The slightly more sand gained in the offshore bar area as compare to the sand loss in the nearshore area might come from the large Pass-A-Grille ebb shoal via northward longshore sand transport.

Sunset Beach: R137-R143

This section of the beach is approximately 5,000 ft long and was recently nourished in the summer of 2010. A vegetated dune field existed before the storm at all of the profiles. This section of the beach was fairly narrow before the storm impact. This section suffered probably the most severe erosion in Pinellas County, with erosion of nearly all the pre-storm dry beach and severe dune scarping. The following changes were measured along this section of the beach:

- 1) The dune field lost 7,700 cubic yards of sand.
- 2) On average, the dune line retreated landward 18.0 ft. At profile R141, due to the impoundment by the groin just north of the profile, the NAVD88 1.3m contour moved seaward 21.3 ft. Substantial dune line retreat was measured at all other profiles, with the largest retreat of 42.6 ft at R139. Profile R139 also suffered severe scour in front of the exposed seawall.
- 3) The dry beach lost 12,000 cubic yards of sand.
- 4) On average, the MHT line moved landward 21.3 ft, with substantial longshore variation ranging from 6.6 ft gain at R141 to 52.2 ft retreat at R139.
- 5) Including the erosion in the nearshore zone, this section lost a total of 43,400 cubic yards of sand.
- 6) The sandbar gained 22,600 cubic yards of sand, considerably less than the overall loss. The sand was likely transported north and contributed to the overall sand gain along the beaches to the north.

Middle Treasure Island: R128-R137

This section of the beach is approximately 8,000 ft long and was not nourished in 2006 or before. A vegetated dune field existed before the storm at most of the profiles. This section comprises probably the widest beach in Pinellas County. The following changes were measured along this section of the beach:

- 1) The dune field gained 11,000 cubic yards of sand. This gain is related to the development of the storm berm (with a peak elevation extending above 1.3 m (4.3 ft) NAVD88).
- 2) The dry beach lost 13,000 cubic yards of sand.
- 3) On average, the MHT line moved landward 10.2 ft, with substantial longshore variation ranging from 2.6 ft gain at R131 to 59.0 ft retreat at R129. This shoreline change pattern is likely related to the attachment point of the John's Pass ebb shoal, which is located at profile R129.
- 4) Including the erosion in the nearshore zone, this section lost a total of 50,100 cubic yards of sand.
- 5) The sandbar gained 63,600 cubic yards of sand, slightly more than the overall loss, likely due to northward longshore transport from the Sunset Beach to the south.

Sunshine Beach: R127-R128

This short section of the beach is approximately 1,000 ft long and was recently nourished in the summer of 2010. A vegetated dune field existed before the storm at both of the profiles. This section of the beach extends to the south jetty of John's Pass. Due to the extensive John's Pass ebb shoal, the profile survey could not extend to the short-term closure depth. Minimal changes in the dune field occurred, likely related to the impoundment effect by the John's Pass south jetty to the northward longshore transport. Overall, 2,100 cubic yards of sand was lost from the dry beach.

The Entire Treasure Island

Overall, the entire Treasure Island suffered dune, dry beach, and nearshore erosion, especially along the Sunset Beach, while the nearshore bar gain substantial amount of sand. Overall along the 14,000 ft studied section of Treasure Island, a total of 3,300 cubic yards of dune sand gain was measured. This small gain was caused by the development of the storm berm, with the peak elevation exceeded the 1.3 m (4.3 ft) NAVD88 at some locations. The dry beach lost 27,100 cubic yards of sand. Substantial erosion also occurred in the nearshore zone, extending to the trough landward of the bar at up to approximately -1.5 m (4.9 ft) NAVD88. Including the dune,

dry beach, and nearshore erosion, the total sand loss along Treasure Island amounted to 93,500 cubic yards. Most of the sand was deposited on the nearshore bar, with a total sand volume gain of 86,200 cubic yards. The slightly higher sand loss was likely deposited on the large John's Pass ebb shoal.

Madeira Beach: R116-R124

This section of the beach is approximately 8,000 ft long and was not nourished in 2006 and before. A vegetated dune field existed before the storm at most of the profiles. Scarping occurred along most sections of the dune field. This section of the beach extends to the north jetty of John's Pass. The following changes were measured along this section of the beach:

- 1) The dune field gained 700 cubic yards of sand. This small gain is related to the development of storm berm (with a peak elevation extending above 1.3 m NAVD88).
- 2) The dry beach lost 22,500 cubic yards of sand.
- 3) On average, the MHT line moved landward 18.4 ft, with substantial longshore variation ranging from 6.4 ft gain at R124 to 47.2 ft retreat at R122. This shoreline change pattern is likely related to the John's Pass north jetty, providing sheltering for R124, while the sheltering zone ended in the vicinity of R122.
- 4) Including the erosion in the nearshore zone, this section lost a total of 29,600 cubic yards of sand.
- 5) The sandbar gained 35,000 cubic yards of sand, slightly more than the overall loss, likely due to northward longshore transport from the large John's Pass ebb shoal to the south.

Redington Beach: R107-R116

This section of the beach is approximately 8,000 ft long and was not nourished in 2006 or before. A vegetated dune field existed before the storm, except at profile R108A. The dune field at R107 and R109 was quite narrow. Severe scour in front of the exposed seawall occurred at profiles R107, R108, and R109. The following changes were measured along this section of the beach:

- 1) The dune field lost 4,300 cubic yards of sand.
- 2) On average, the dune line retreated landward 15.1 ft, with substantial longshore variations ranging from 1.0 ft (R108A) to 23.3 ft (R111) retreat, largely influenced by the pre-storm dune characteristics.
- 3) The dry beach lost 19,200 cubic yards of sand.
- 4) On average, the MHT line moved landward 18.4 ft, with substantial longshore variation ranging from 13.1 ft gain at R113 to 40.3 ft retreat at R108A. The excessive erosion at

profile R108a is related to the scour at the exposed seawall. The shoreline gain at R113 is related to the exceptional development of ridge and runnel feature along this profile. Ridge and runnel are typical morphological features associated with natural post-storm beach recovery.

- 5) Including the erosion in the nearshore zone, this section lost a total of 38,600 cubic yards of sand.
- 6) The sandbar gained 48,800 cubic yards of sand, slightly more than the overall loss, likely due to northward longshore sand transport from the large John's Pass ebb shoal to the south.

North Redington Beach: 100-R107

This section of the beach is approximately 7,000 ft long and was nourished in 2006. This section comprises the southern end of the 2006 beach nourishment. The section is characterized by a rather rapid southward decreasing beach width. Profiles R106 and R107 at the southern end of this section had quite narrow beach before the storm impact. The following changes were measured along this section of the beach:

- 1) The dune field lost 500 cubic yards of sand. The small loss is largely controlled by the absence of dune field along most of this section of beach.
- 2) The dry beach lost 21,800 cubic yards of sand.
- 3) On average, the mean high tide line moved landward 33.8 ft, with substantial longshore variation ranging from 9.8 ft retreat at R100A to 46.6 ft retreat at R101. The excessive erosion at profile R101 is likely related to the Redington breakwater just to the north.
- 4) Including the erosion in the nearshore zone, this section lost a total of 59,400 cubic yards of sand.
- 5) The sandbar gained 41,000 cubic yards of sand, considerably less than the overall loss. Some of the sand was likely transported northward and contributed to sand accumulation over the bar along the beaches to the north, as discussed in the following.

Indian Shores: R89-R100

This section of the beach is approximately 10,000 ft long and was nourished in 2006. A vegetated dune field existed before the storm. Scarping occurred along most sections of the dune field. Indian Shores comprises one of the most severely eroded sections along Sand Key due to the impact of Tropical Storm Debby. The following changes were measured along this section of the beach:

- 1) The dune field lost 6,300 cubic yards of sand.

- 2) On average, the dune line retreated landward 19.4 ft, with substantial longshore variations ranging from 8.4 ft (R94) to 32.1 ft (R100) retreat, largely influenced by the pre-storm dune characteristics.
- 3) The dry beach lost 32,200 cubic yards of sand.
- 4) On average, the MHT line moved landward 34.4 ft, with substantial longshore variation ranging from 22.3 ft retreat at R92 to 48.5 ft retreat at R100. The excessive erosion at profile R100 is likely related to the Redington breakwater just to the south.
- 5) Including the erosion in the nearshore zone, this section lost a total of 98,400 cubic yards of sand.
- 6) The sandbar gained 100,000 cubic yards of sand, slightly more than the overall loss, likely due to northward longshore transport from the beach further south.

Headland: R82-R89

This protruding section of the beach is approximately 7,000 ft long and was nourished in 2006. A nearly continuous vegetated dune field existed before the storm. Scarping occurred along most sections of the dune field. The headland section suffered severe erosion due to the impact of Tropical Storm Debby. The following changes were measured along this section of the beach:

- 1) The dune field lost 5,500 cubic yards of sand.
- 2) On average, the dune line retreated landward 15.1 ft, with substantial longshore variations ranging from 2.3 ft (R89) to 27.2 ft (R87) retreat, largely influenced by the pre-storm dune characteristics.
- 3) The dry beach lost 15,800 cubic yards of sand.
- 4) On average, the MHT line moved landward 28.2 ft, with substantial longshore variation ranging from 11.5 ft retreat at R82 to 41.3 ft retreat at R88.
- 5) Including the erosion in the nearshore zone, this section lost a total of 58,600 cubic yards of sand.
- 6) The sandbar gained 61,400 cubic yards of sand, slightly more than the overall loss, likely due to northward longshore transport from the beach further south.

Indian Rocks Beach: R71-R82

This section of the beach is approximately 12,000 ft long and was nourished in 2006. A nearly continuous vegetated dune field existed before the storm. Scarping occurred along most sections of the dune field. Indian Rocks beach suffered substantial erosion due to the impact of Tropical Storm Debby. The following changes were measured along this section of the beach:

- 1) The dune field lost 12,100 cubic yards of sand.

- 2) On average, the dune line retreated landward 12.5 ft, with considerable longshore variations ranging from 2.3 ft (R71A) to 24.9 ft (R75) retreat.
- 3) The dry beach lost 15,300 cubic yards of sand.
- 4) On average, the MHT line moved landward 10.2 ft, with substantial longshore variation ranging from 11.7 ft gain at R71 (likely due to northward longshore transport) to 20.7 ft loss at R79.
- 5) Including the erosion in the nearshore zone, this section lost a total of 86,900 cubic yards of sand.
- 6) The sandbar gained 100,800 cubic yards of sand, slightly more than the overall loss, likely due to northward longshore transport from the beach further south.

Belleair Shore: R66-R71

This section of the beach is approximately 6,000 ft long and was not nourished in 2006 and before. The beach was quite narrow before the storm, mostly less than 30 ft wide with little to no dunes. Different from most of the sections discussed above, this section gained sand on the dry beach. The following changes were measured along this section of the beach:

- 1) The dune field lost 2,800 cubic yards of sand.
- 2) On average, the dune line retreated landward 3.9 ft, with considerable longshore variations ranging from nearly zero to 7.9 ft retreat.
- 3) The dry beach gained 6,800 cubic yards of sand.
- 4) On average, the MHT line moved seaward 10.5 ft, ranging from 3.0 ft gain to 17.7 ft gain. In other words, the dry beach along Belleair Shore became wider due to Tropical Storm Debby.
- 5) Including the erosion in the nearshore zone, this section lost 29,900 cubic yards of sand.
- 6) The sandbar gained 38,600 cubic yards of sand, slightly more than the overall loss, likely due to northward longshore transport from the beach further south.

North Sand Key: R55-R66

This section of the beach is approximately 11,000 ft long, extending southward from the long south jetty of Clearwater Pass. The situation at this section is complicated by the ongoing beach nourishment. Profiles R58 through R61 are not included in the present data analysis due to the recent nourishment (at the time of data collection). In addition, the impoundment at the Clearwater Pass south Jetty which is about 3000 ft north of R55 also complicated the beach behavior. With the above complications in mind, the following changes were summarized along this section of the beach:

- 1) The dune field lost 5,600 cubic yards of sand, mostly from profiles south of R61.
- 2) On average the dune line moved landward 6.2 ft, also mostly from profiles south of R61.
- 3) The dry beach gained 2,500 cubic yards of sand, largely due to the infusion of sand by the nourishment and the impoundment of the Clearwater Pass south jetty.
- 4) Overall beach erosion and deposition over the sandbar could not be calculated reliably due to the ongoing beach nourishment and the large Clearwater Pass ebb shoal, which made it difficult to survey to short-term closure depth.

The Entire Sand Key

Overall, all of Sand Key suffered dune, dry beach, and nearshore erosion, while the nearshore bar gain substantial amount of sand. Overall along the 69,000 ft studied section of Sand Key, a total of 36,400 cubic yards of dune sand was eroded, in addition to 117,500 cubic yards of sand eroded from the dry beach. Substantial erosion also occurred in the nearshore zone, extending to the trough landward of the bar at up to approximately -1.5 m (4.9 ft) NAVD88. Including the dune, dry beach, and nearshore erosion, the total sand loss along Sand Key amounted to 424,000 cubic yards. Almost all of the sand seemed to have been deposited on the nearshore bar, with a total sand volume gain of 445,600 cubic yards. The slightly higher gain on the nearshore bar may be related to the northward sand transport from the John's Pass ebb shoal.

Summary

The long-lasting Tropical Storm Debby induced severe beach and dune erosion along the entire Pinellas County coast. Dune erosion in the form of extensive dune scarping was measured along nearly the entire Sand Key, resulting in a total dune-sand volume loss of 36,400 cubic yards. Dune scarp was developed along most of Sand Key beach, with section-averaged dune line retreat ranging from 4 to 19 ft. The dry beach along Sand Key lost 117,500 cubic yards of sand, with section-averaged Mean High Tide line retreat landward ranging from 10 to 35 ft. Substantial erosion also occurred in the nearshore zone, including the sand loss in the nearshore zone, the overall sand volume loss on Sand Key was 424,000 cubic yards. Most of this sand volume loss can be accounted for by the sand gain over the nearshore bar, where an overall gain of 445,500 cubic yards was measured.

Dune erosion was measured along the southern portion of Treasure Island, i.e., the Sunset Beach. Dune scarp was developed along Sunset Beach, with an average dune line retreat of 18 ft. The dry beach along Treasure Island lost 27,100 cubic yards of sand, with section-averaged Mean High Tide line change ranging from 25 ft gain at Sunshine Beach to 21 ft landward retreat at Sunset Beach. Substantial erosion also occurred in the nearshore zone, with an overall sand volume loss on Treasure Island of 94,000 cubic yards, if including the sand loss in the nearshore

zone. Most of this sand volume loss can be accounted for by the sand gain over the nearshore bar, where an overall gain of 86,200 cubic yards was measured.

Dune erosion was also measured along the southern portion of Long Key, i.e., the Pass-A-Grille Beach. Dune scarp was developed along most of the Pass-A-Grille Beach, with an average dune line retreat of 12 ft, especially north of the exposed seawall in front of the shop there. The dry beach along Long Key lost 58,700 cubic yards of sand, with section-averaged Mean High Tide line change ranging from 11 ft landward retreat at Upham Beach to 38 ft landward retreat at Pass-A-Grille Beach. Substantial erosion also occurred in the nearshore zone, with an overall sand volume loss on Long Key of 113,400 cubic yards, if including the sand loss in the nearshore zone. Most of this sand volume loss can be accounted for by the sand gain over the nearshore bar, where an overall gain of 125,900 cubic yards was measured. Similar to the case along Sand Key, the slightly additional sand gain over the nearshore bar may be attributed to the sand transported northward from the large Pass-A-Grille ebb shoal.

Overall, along the three studied barrier islands, the dune field, defined here as the portion of the beach that is above 1.3 m (4.3 ft) NAVD88 lost a total of 25,000 cubic yards of sand. The dry beach, defined here as the portion of the beach between 1.3 m (4.3 ft) NAVD88 and 0.3 m (1.0 ft) NAVD88 (or Mean High Tide Line), lost 203,000 cubic yards of sand. A substantial amount of sand was also move seaward from the nearshore area (above -1.5 m (4.9 ft) NAVD88 contour) to the nearshore bar. Combining sand losses from the dune field, the dry beach, and the nearshore zone, a total of 631,000 cubic yards of sand were lost. Almost all the sand lost can be accounted for by the deposition over the nearshore bar, with a total gain of 658,000 cubic yards of sand. The slightly more sand gain can probably be attributed to sand supplies from the ebb shoals of John's Pass and Pass-A-Grille Pass. Table 1 summarized the sand volume changes along the three barrier islands.

Many sections of the three barrier islands are comprised of nourished beaches. Table 2 summarizes the sand volume changes along the nourished beaches. Overall, along the nourished beaches at the three barrier islands, a total of 36,000 cubic yards of sand was eroded from the dune field. The dry beach lost 124,000 cubic yards of sand. Combining sand losses from the dune field, dry beach, and nearshore zone, a total of 419,000 cubic yards of sand were lost from the nourished beaches. The nearshore bar gained 389,000 cubic yards of sand, accounting for nearly the entire amount of sand lost.

Since the storm approached the coast from a highly oblique angle from the south, Debby induced a substantial northward longshore sand transport during three days, as observed during the storm passage. This is opposite to the long-term general southward trend of longshore sand transport. The beach changes clearly reflected the influence of northward longshore transport at the three barrier islands. On Long Key, the beach at the southern end, Pass-A-Grille beach, experienced severe beach and dune erosion, while the chronic erosional hot spot Upham Beach at the northern end, experienced relatively less severe erosion (Tables 1 and 2). Similar trend was

observed along Treasure Island. The Sunset Beach at the southern end experienced severe beach and dune erosion, while the Sunshine Beach at the northern end, a chronic erosional hot spot, fared much better than Sunset Beach (Tables 1 and 2).

Along the long Sand Key, the southern portions of the barrier island, Madeira Beach and Redington Beach, have been stable over the last two decades, and therefore have not been nourished recently. These two sections of the beach suffered severe beach and dune erosion. The nourished beaches south of the headland experienced the most severe erosion along Sand Key. Towards the northern end of Sand Key, e.g., Belleair Shore, benefited from the northward longshore sand transport, resulting in volume gain over the dry beach. The erosional hot spot, North Sand Key, was being nourished during the passage of the storm. Both the pre- and post-storm beach surveys were influenced by the on-going beach nourishment. The impact of the storm could not be accurately assessed.

Table 1. Volume Changes Measured along the Long Key, Treasure Island, and Long Key

			Volume changes				MHT line change
			Dune	dry beach	overall loss	overall gain	
<u>Long Key Barrier Island:</u>			Cu. yds	Cu. yds	Cu. yds	Cu. yds	ft
Pass-A-Grille Beach:	R160-R165:	nourished in 2004	1500	-22100	-36500	22900	-25.6
Middle Long Key:	LK6-R160:	not nourished	6400	-31500	-64000	82600	-15.1
Upham Beach:	LK1B-LK6:	nourished in 2010, T-groins	270	-5100	-12900	20400	-10.8
Total Long Key			8170	-58700	-113400	125900	
<u>Treasure Island Barrier Island:</u>							
Sunset Beach:	R137-R143:	nourished in 2010	-7700	-12000	-43400	22600	-21.3
Middle Treasure Island:	R128-R137:	not nourished	11000	-13000	-50100	63600	-10.2
Sunshine Beach:	R127-R128:	nourished in 2010		-2100			
Total Treasure Island			3300	-27100	-93500	86200	
<u>Sand Key Barrier Island:</u>							
Madeira Beach:	R116-R124:	not nourished in 2006	700	-22500	-29600	35000	-18.4
Redington Beach:	R107-R116:	not nourished in 2006	-4300	-19200	-38600	48800	-18.4
North Redington Beach:	R100-R107:	nourished in 2006	-500	-21800	-59400	41000	-33.8
Indian Shores:	R89-R100:	nourished in 2006	-6300	-32200	-98400	100000	-34.4
Headland:	R82-R89:	nourished in 2006	-5500	-15800	-58400	61400	-28.2
Indian Rocks Beach:	R71-R82:	nourished in 2006	-12100	-15300	-86900	100800	-10.2
Belleair Shore:	R66-R71:	not nourished in 2006	-2800	6800	-29900	38600	10.5
North Sand Key:	R55 – R66:	nourished in 2006 and now	-5600	2500	-22800	20000	
Total Sand Key			-36400	-117500	-424000	445600	

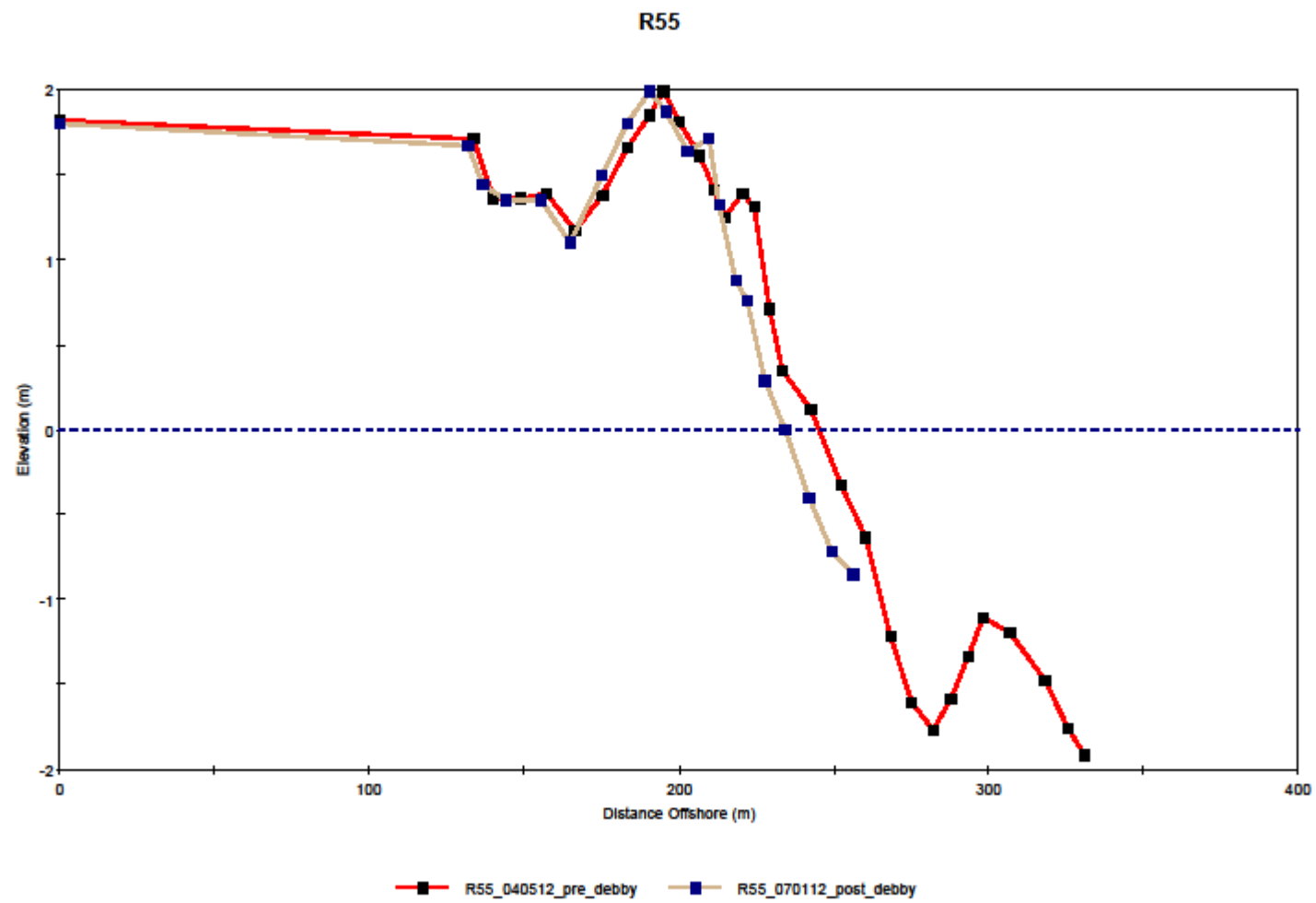
Table 2. Volume Changes Measured along nourished sections of Long Key, Treasure Island, and Long Key

			Volume changes				MHT line change
			Dune	dry beach	overall loss	overall gain	
<u>Long Key Barrier Island:</u>			Cu. yds	Cu. yds	Cu. yds	Cu. yds	ft
Pass-A-Grille Beach:	R160-R165:	nourished in 2004	1500	-22100	-36500	22900	-25.6
Upham Beach:	LK1B-LK6:	nourished in 2010, T-groins	270	-5100	-12900	20400	-10.8
Total Nourished Long Key			1770	-27200	-49400	43300	
<u>Treasure Island Barrier Island:</u>							
Sunset Beach:	R137-R143:	nourished in 2010	-7700	-12000	-43400	22600	-21.3
Sunshine Beach:	R127-R128:	nourished in 2010		-2100			
Total Nourished Treasure Island			-7700	-14100	-43400	22600	
<u>Sand Key Barrier Island:</u>							
North Redington Beach:	R100-R107:	nourished in 2006	-500	-21800	-59400	41000	-33.8
Indian Shores:	R89-R100:	nourished in 2006	-6300	-32200	-98400	100000	-34.4
Headland:	R82-R89:	nourished in 2006	-5500	-15800	-58400	61400	-28.2
Indian Rocks Beach:	R71-R82:	nourished in 2006	-12100	-15300	-86900	100800	-10.2
North Sand Key:	R55 – R66:	nourished in 2006 and now	-5600	2500	-22800	20000	
Total Nourished Sand Key			-30000	-82600	-325900	323200	

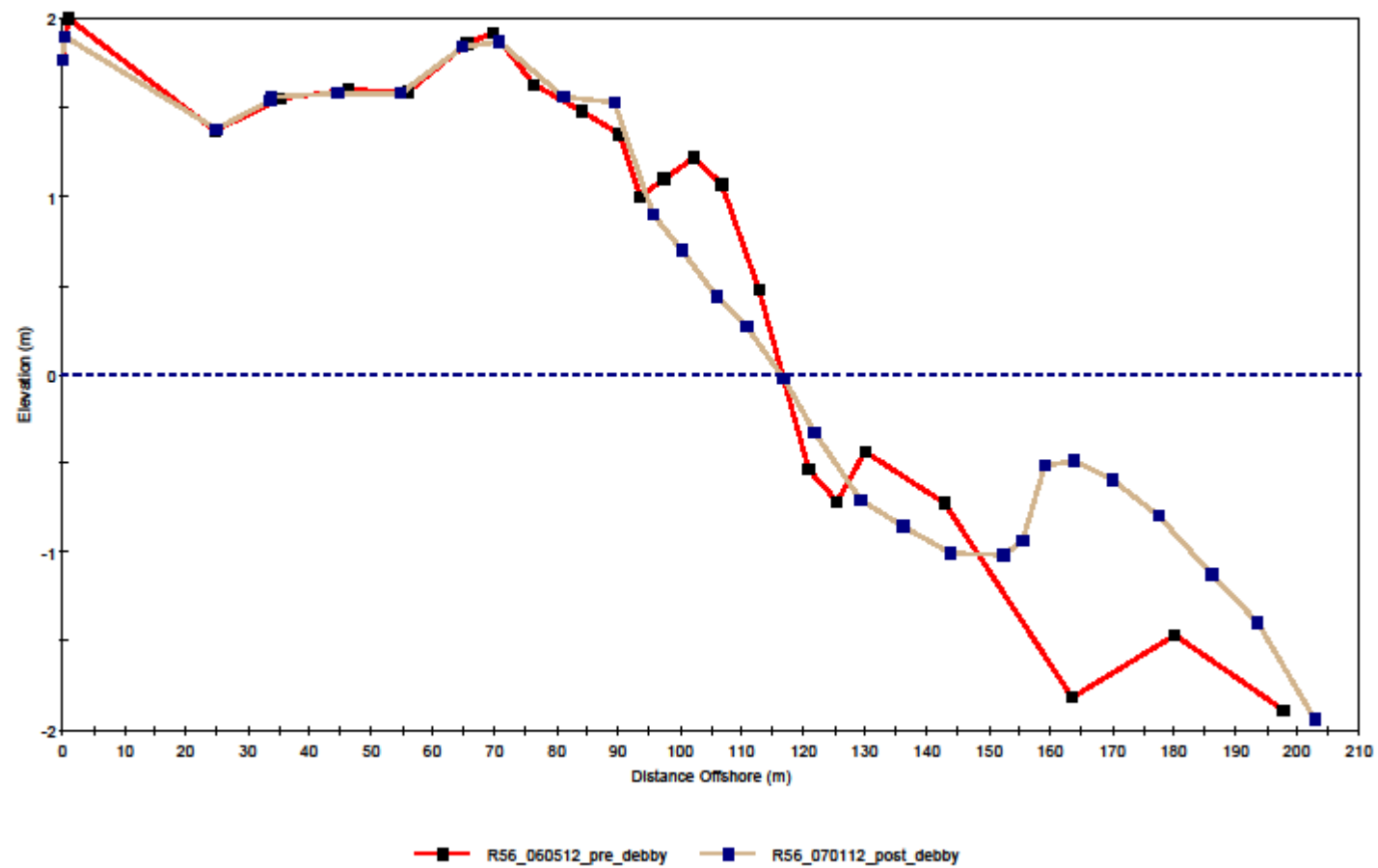
Appendix

Pre- and Post-Debby Beach and Nearshore Profiles

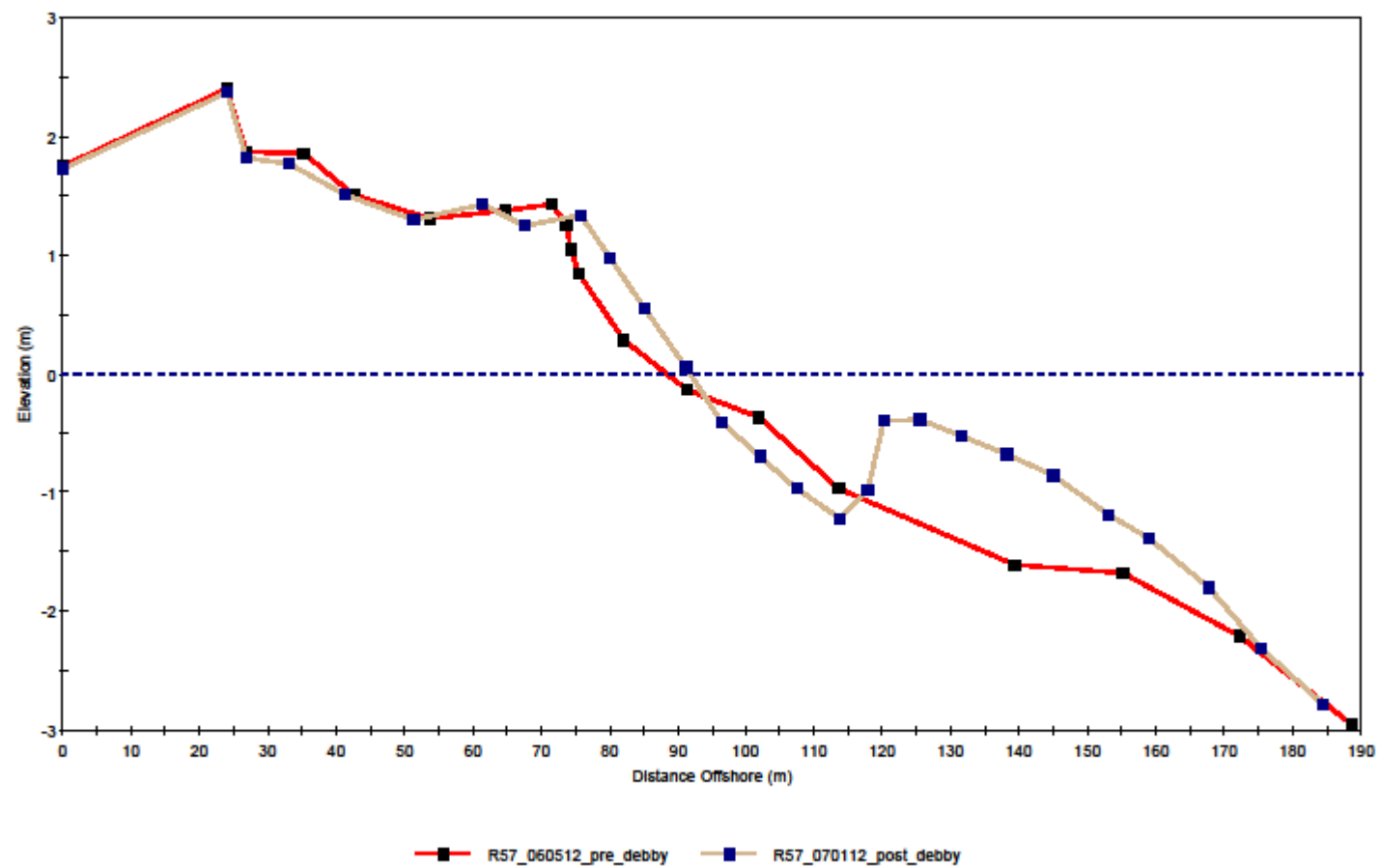
Sand Key

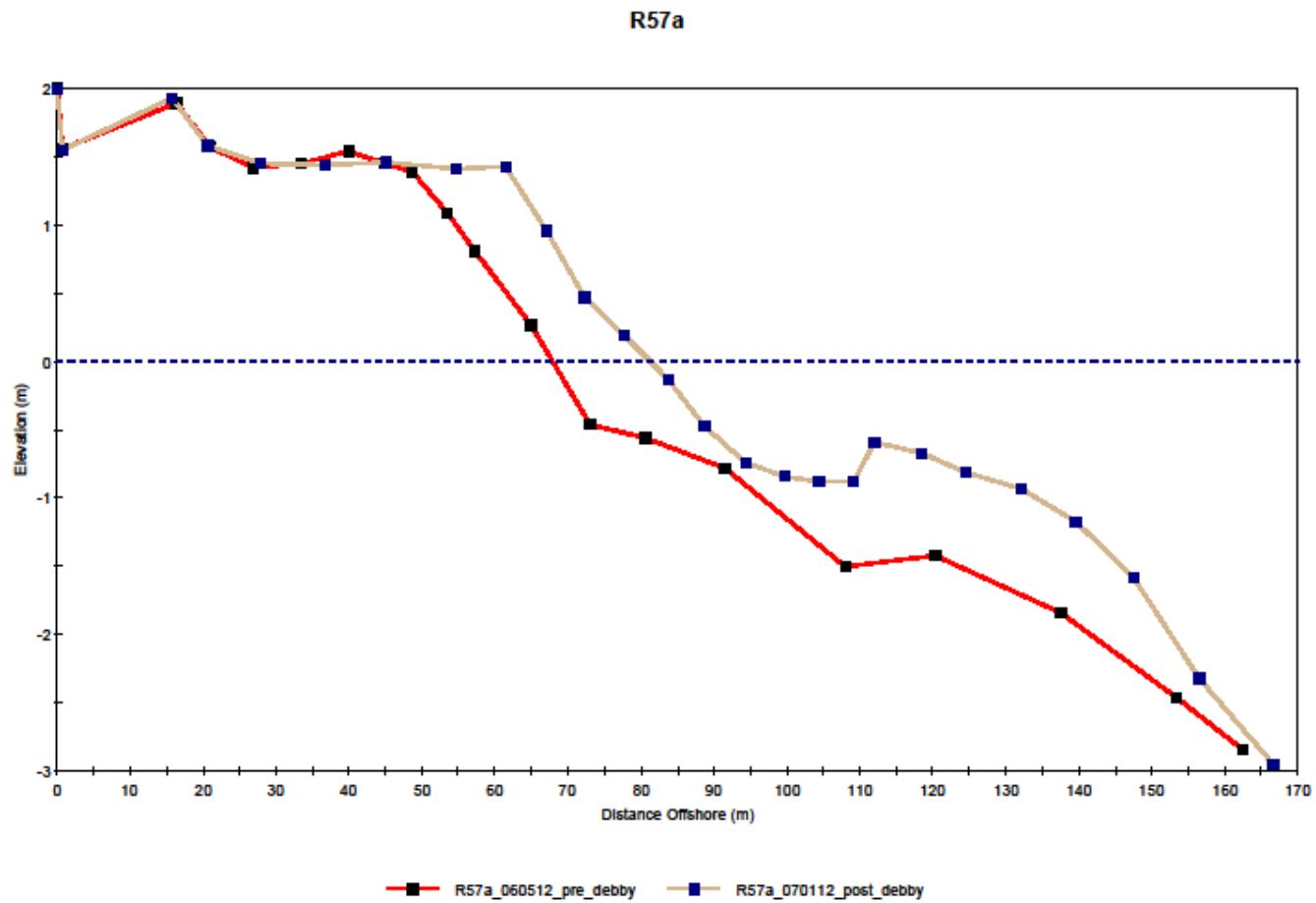


R56

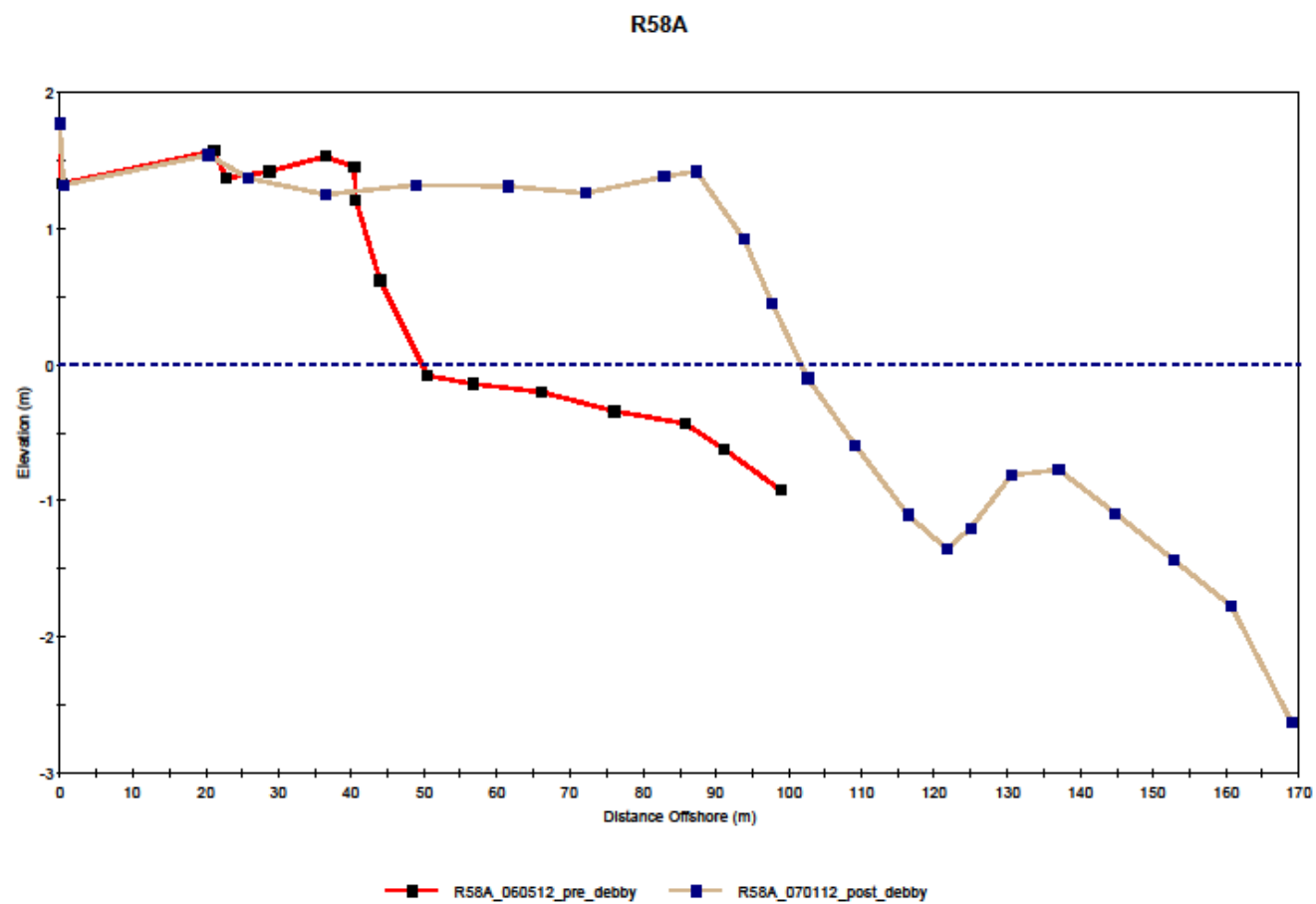


R57

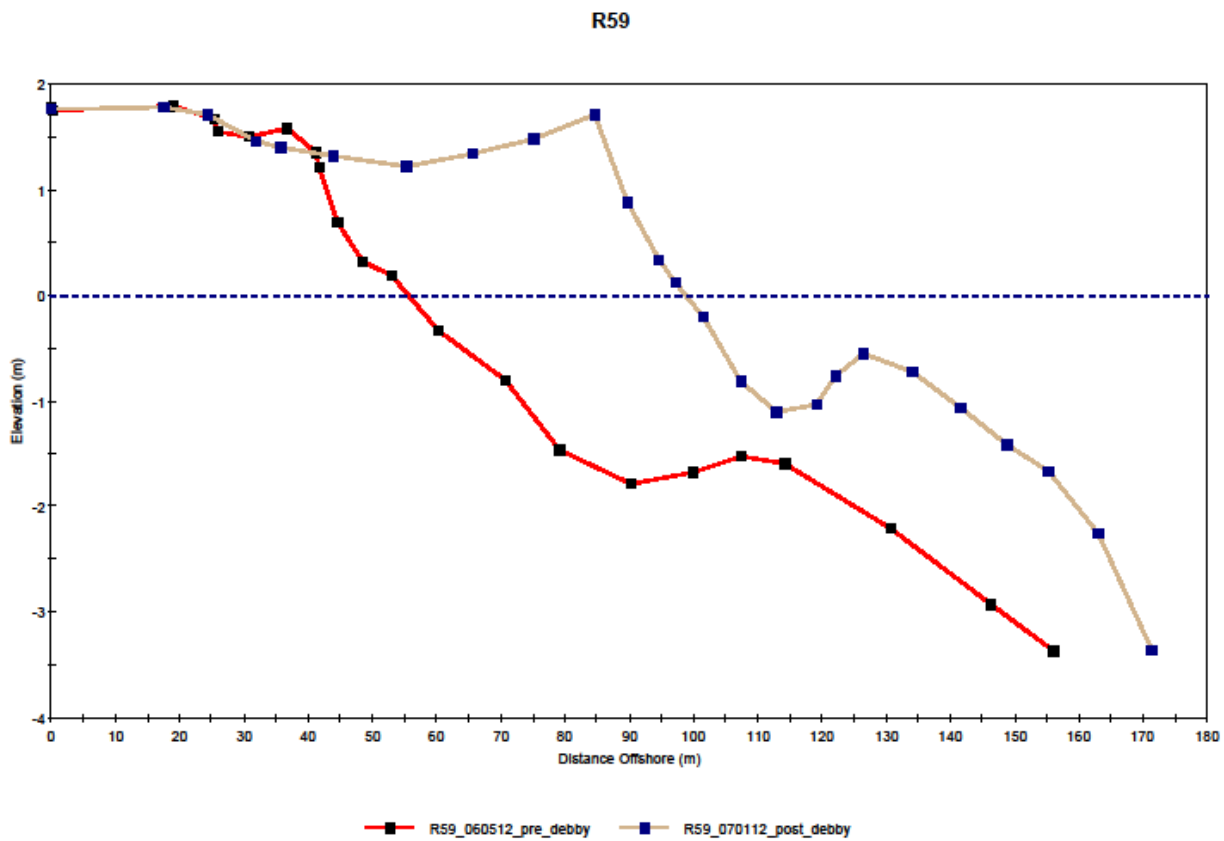




Profile nourished just before storm

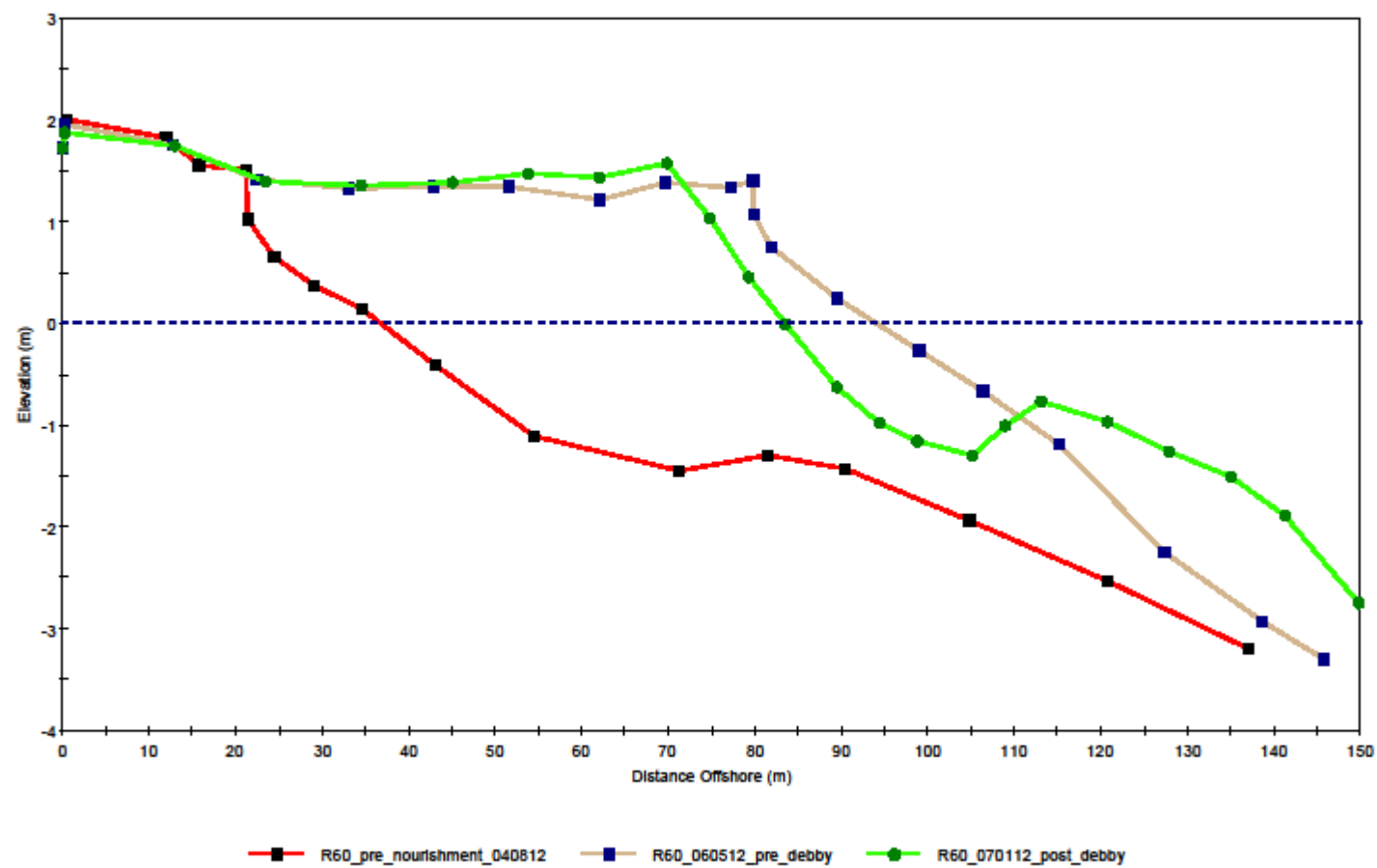


Profile nourished just before storm

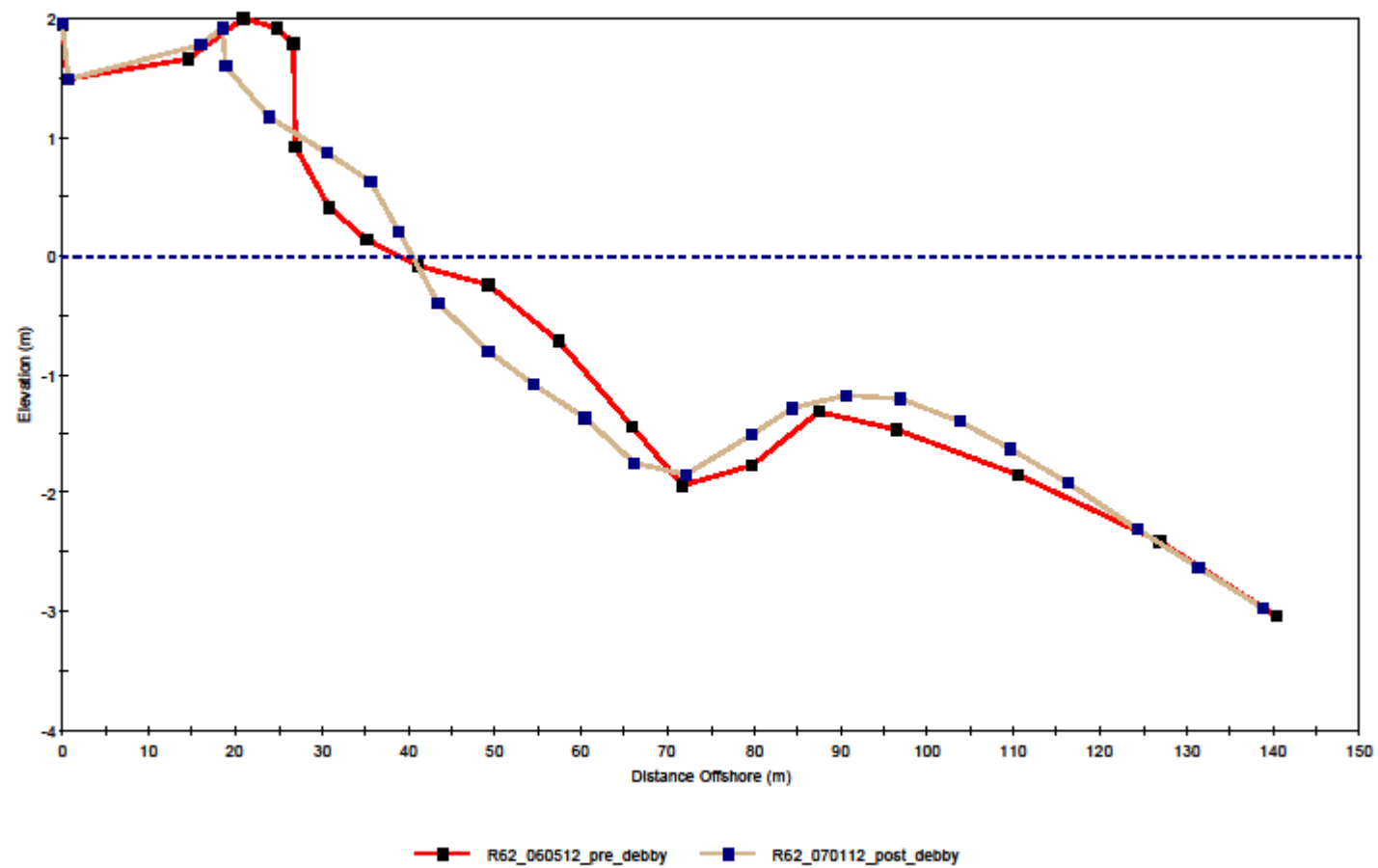


Profile nourished just before storm

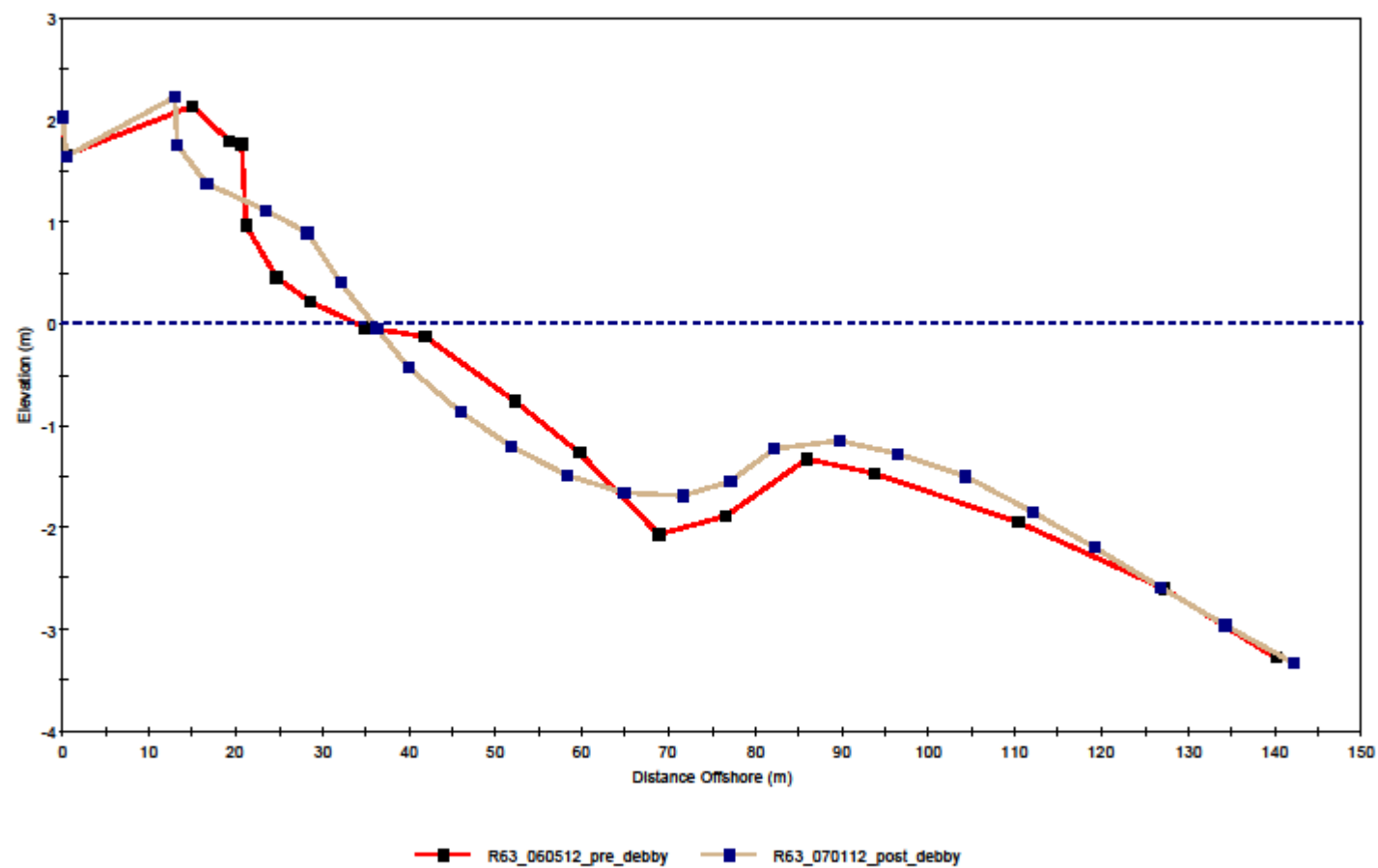
R60



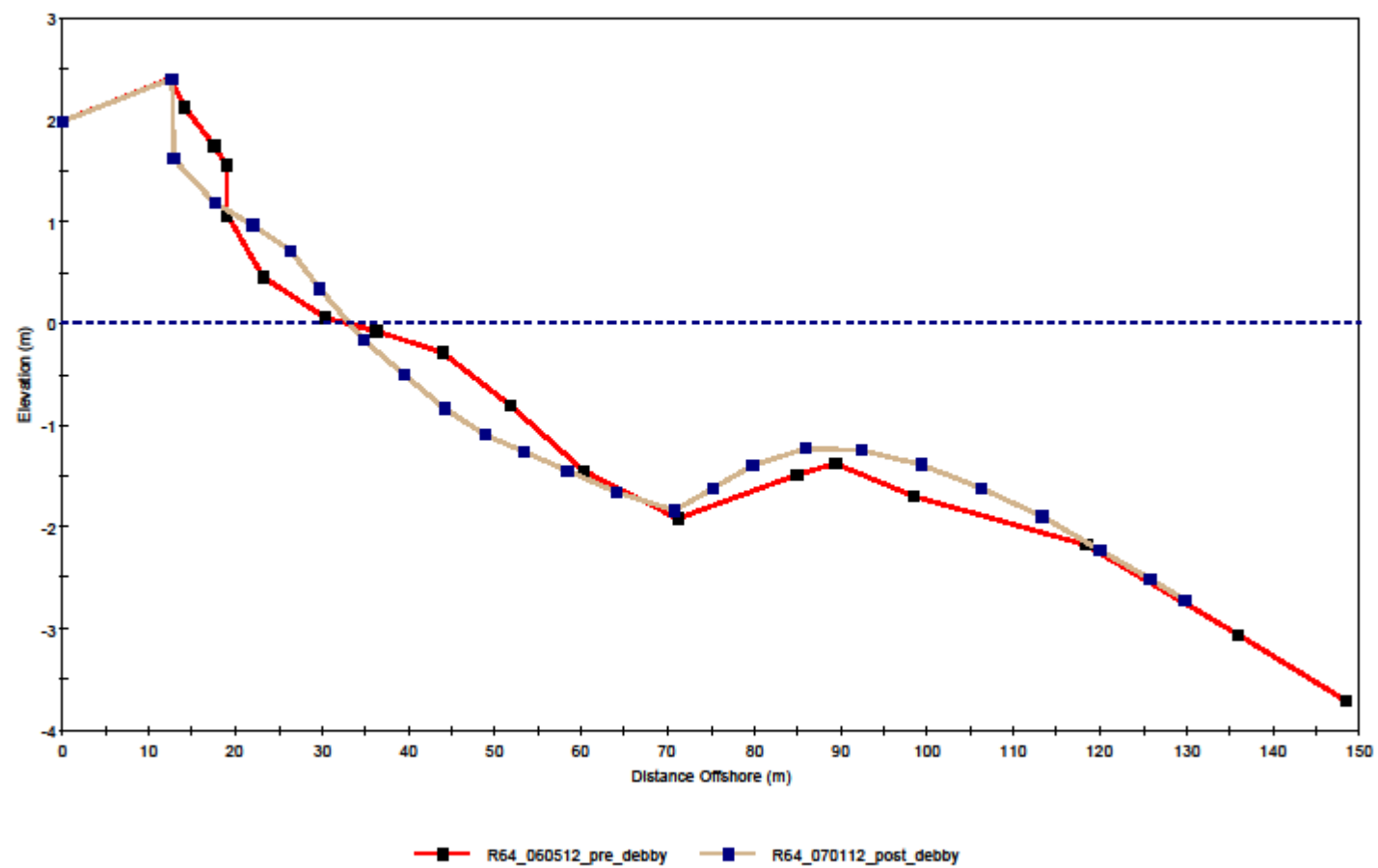
R62



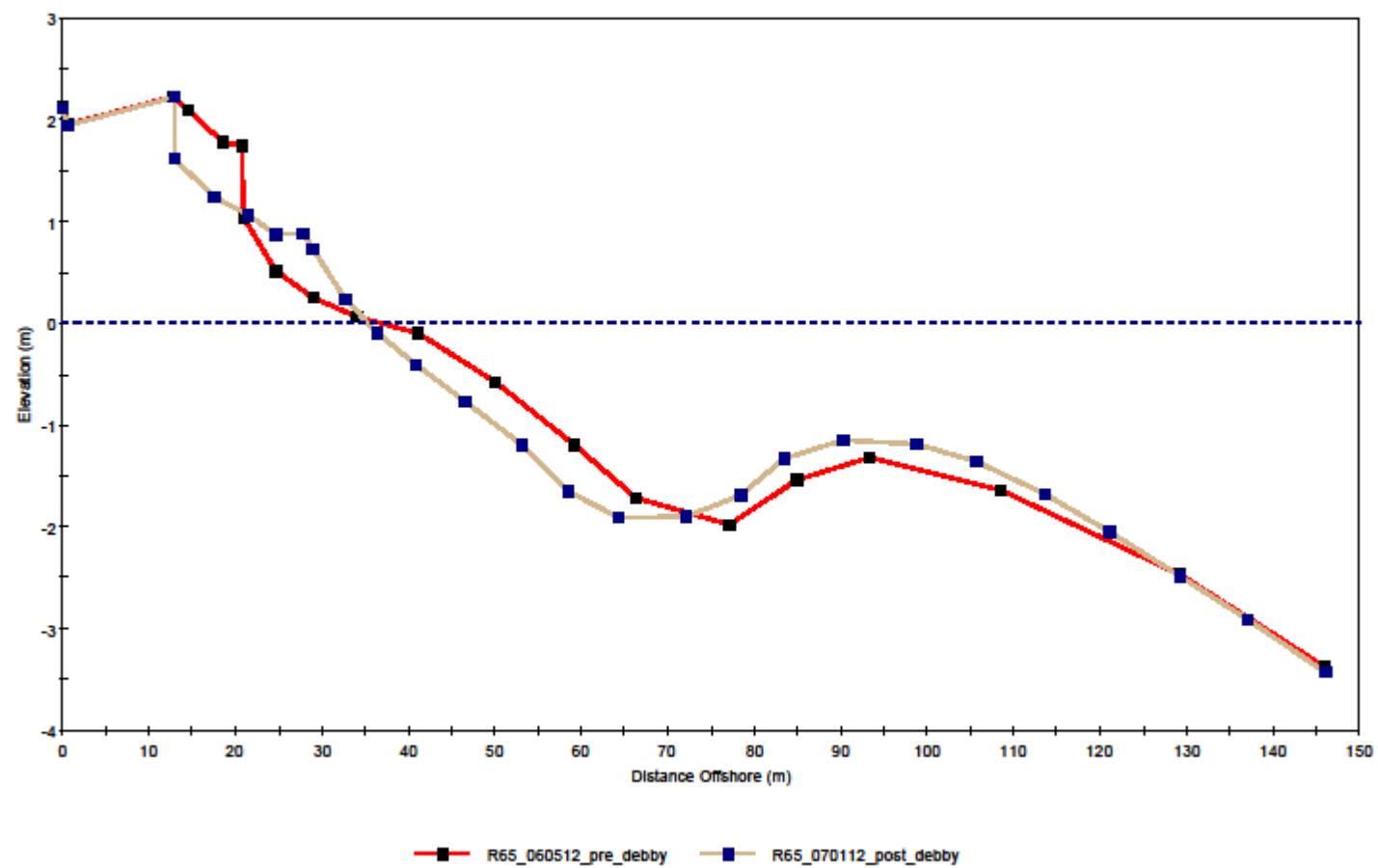
R63



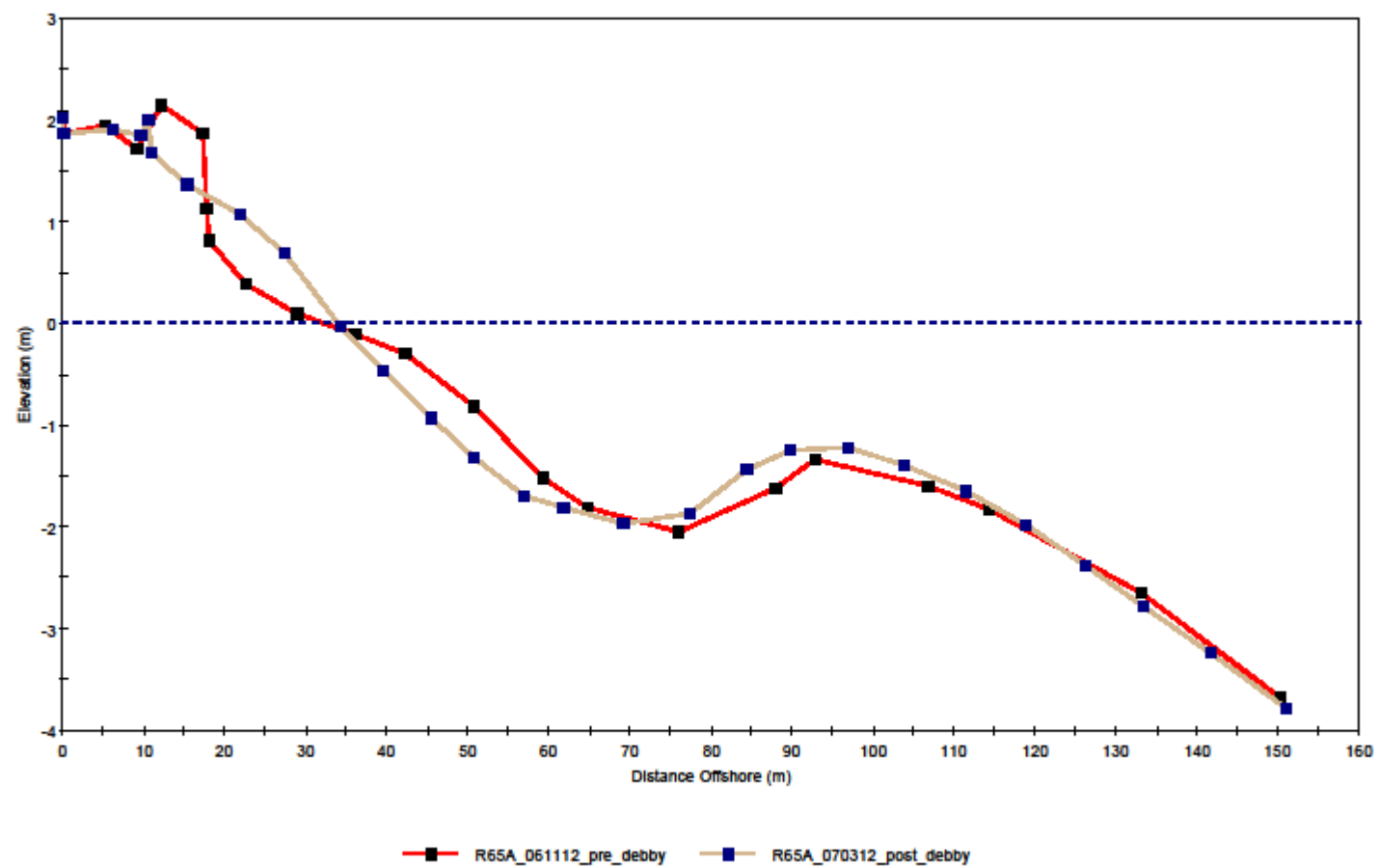
R64



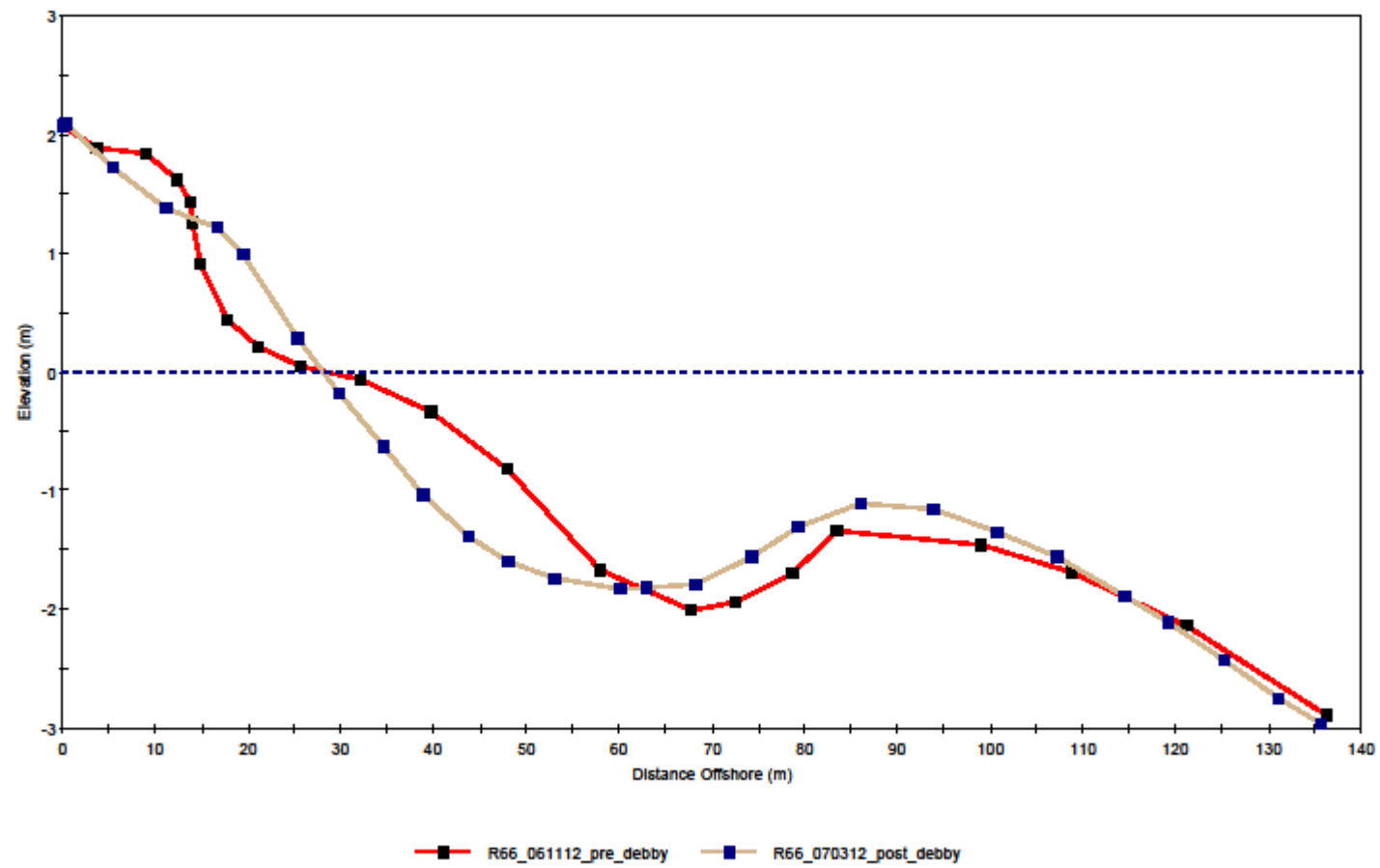
R65



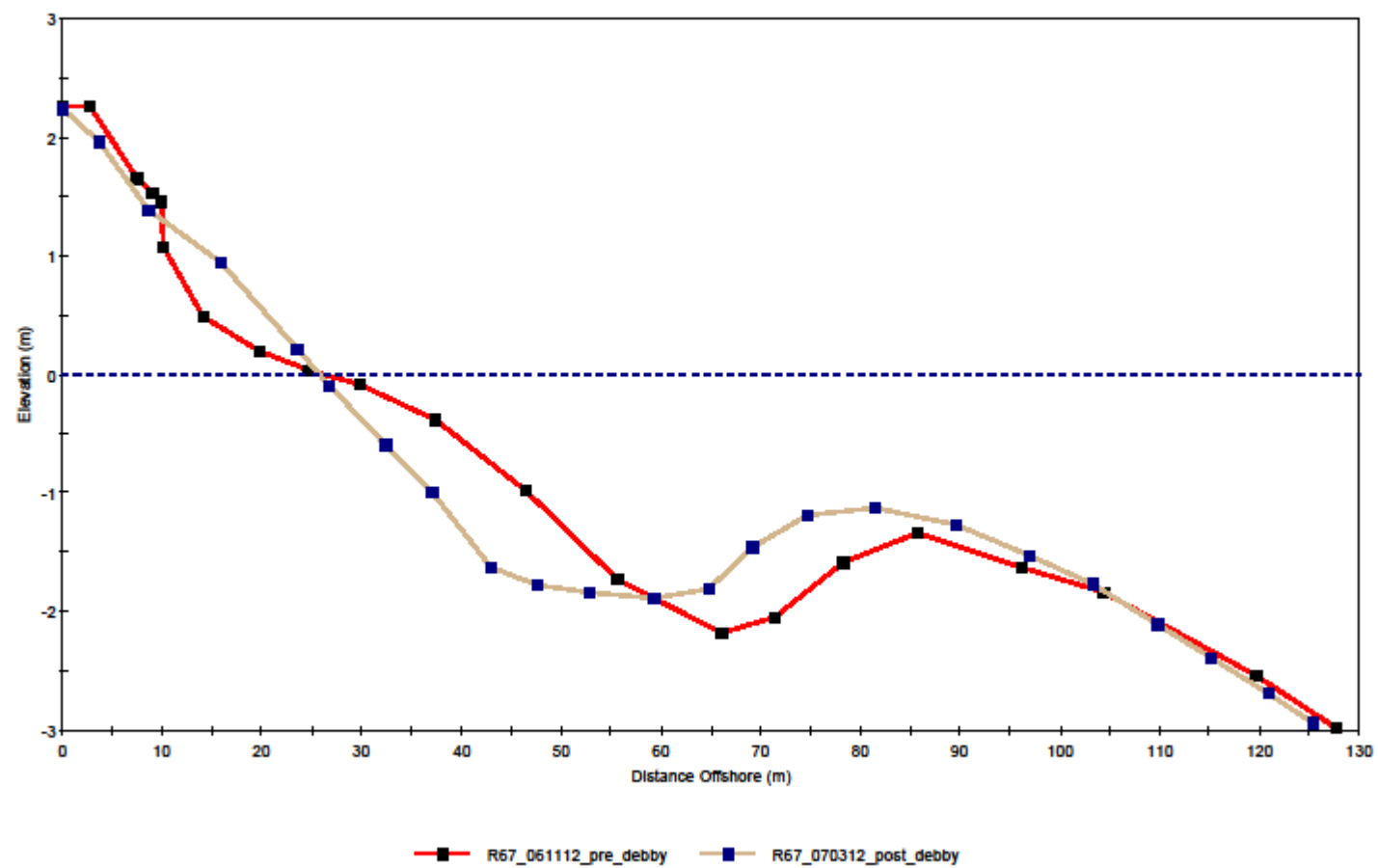
R65A



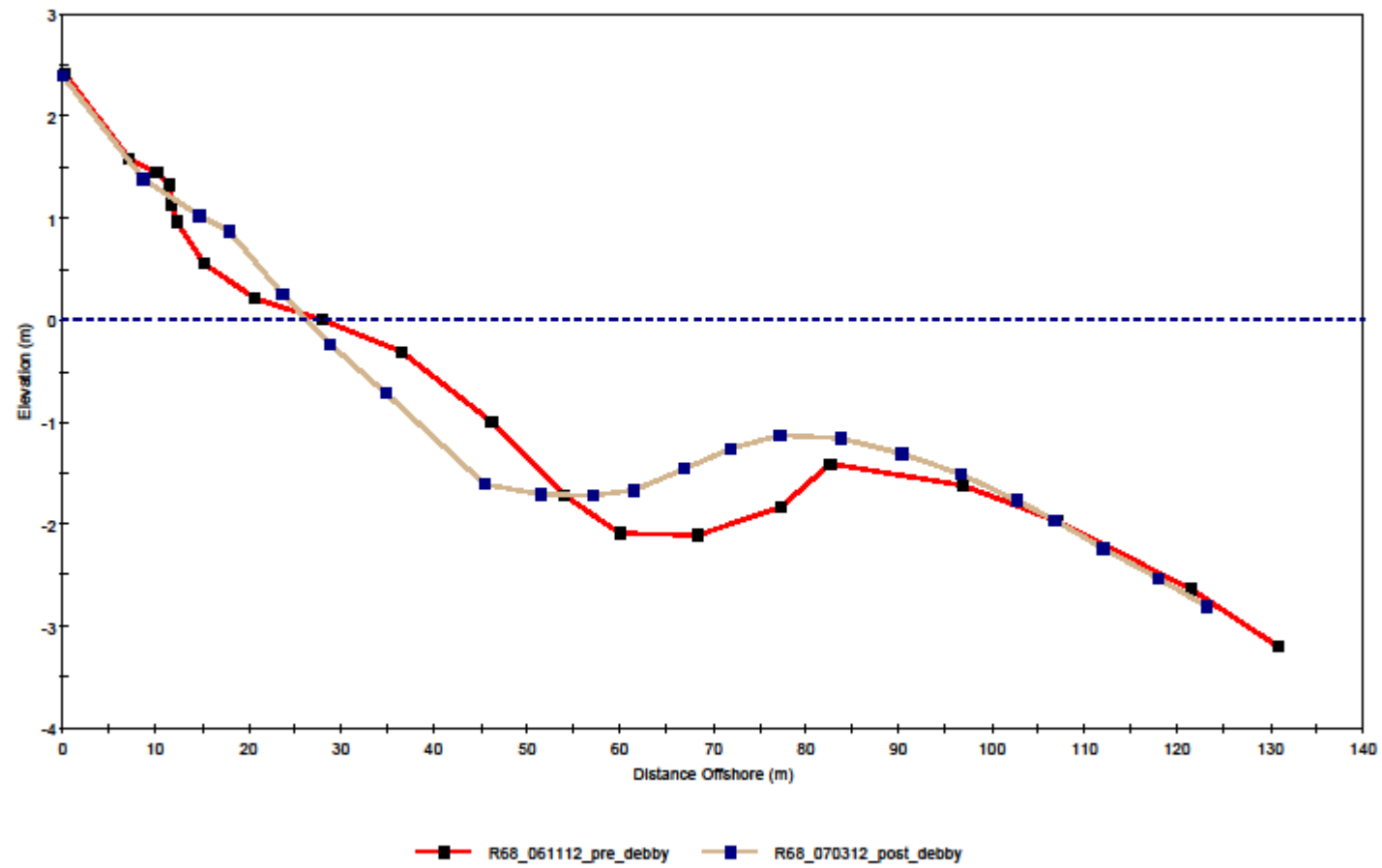
R66



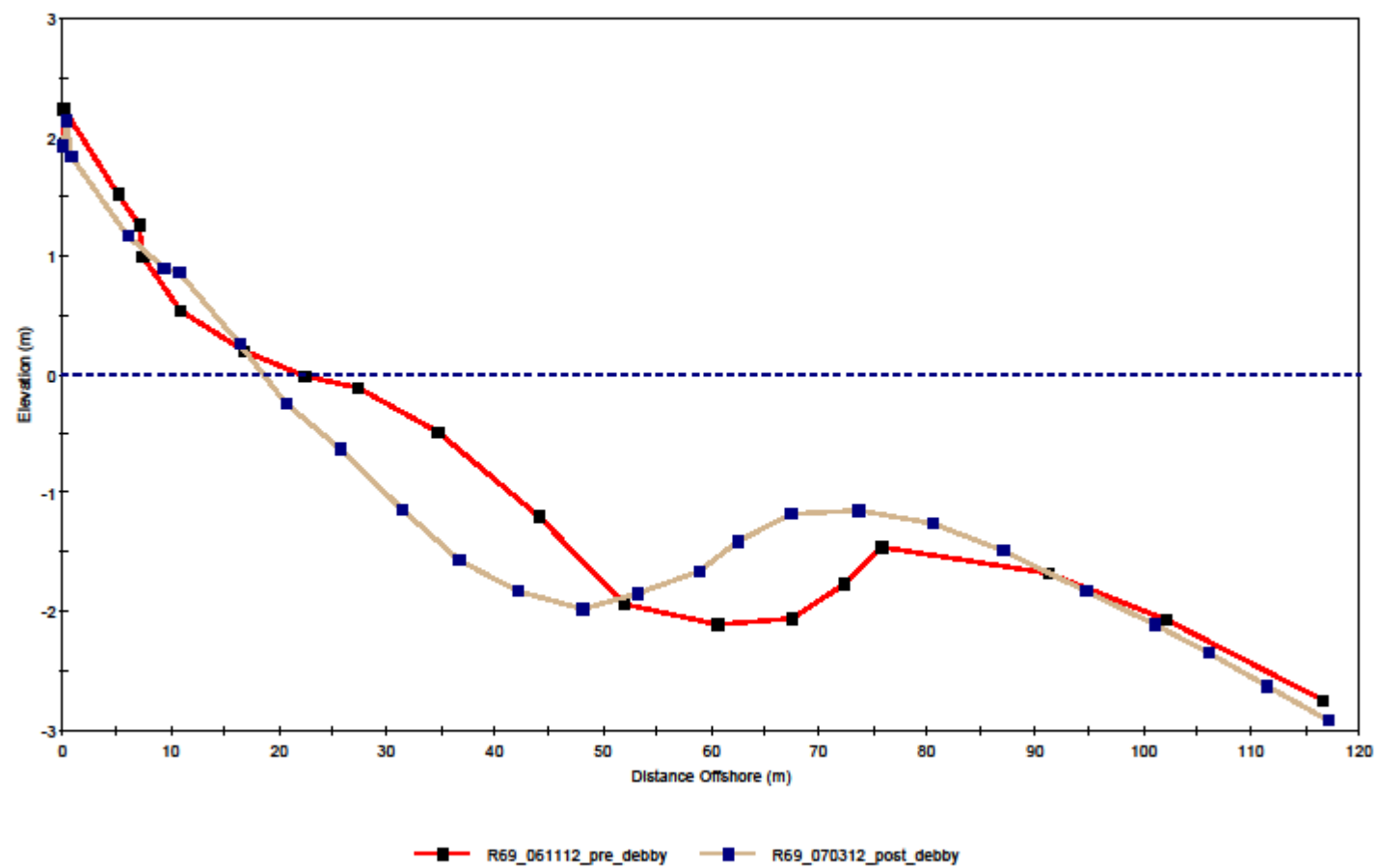
R67



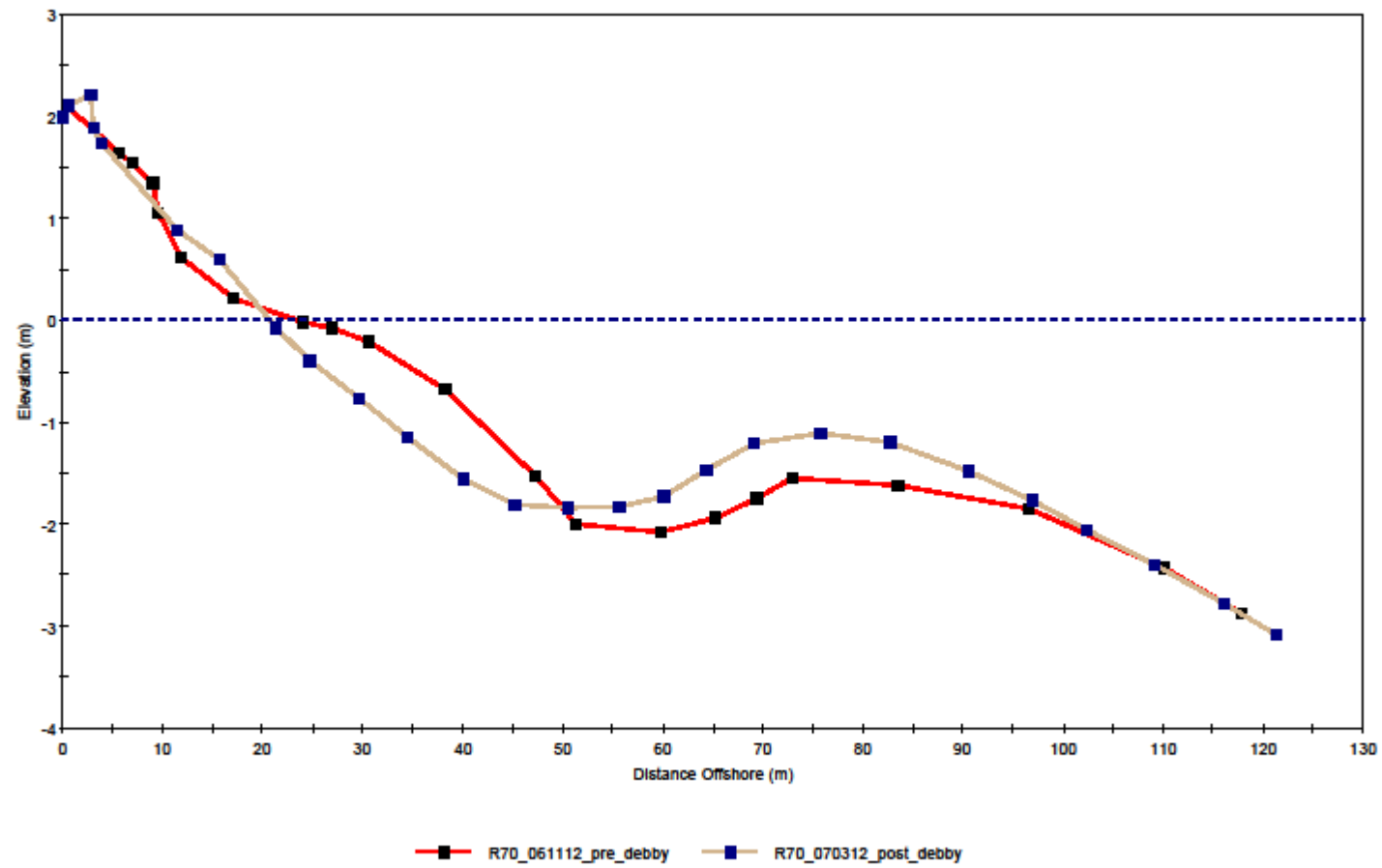
R68



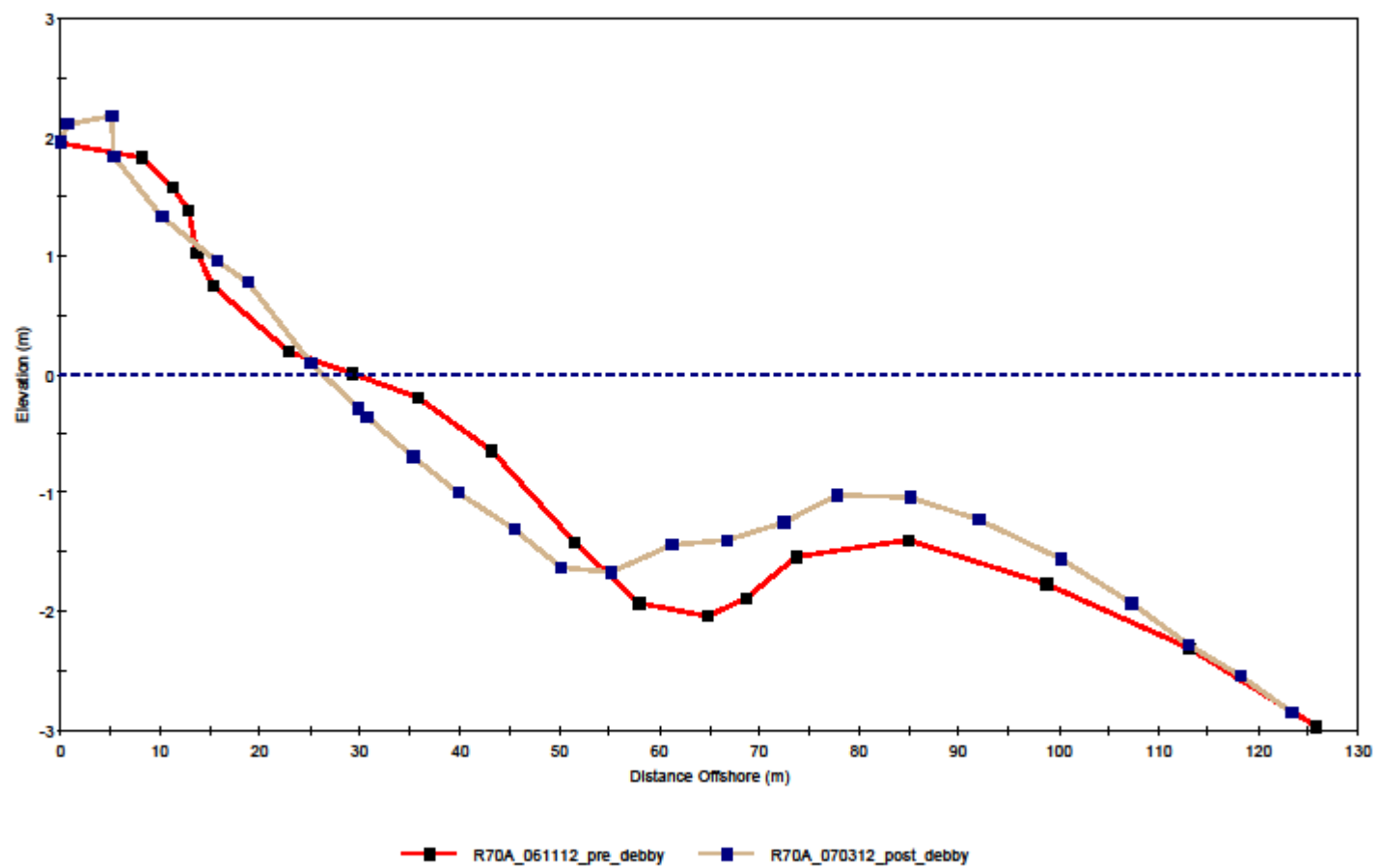
R69



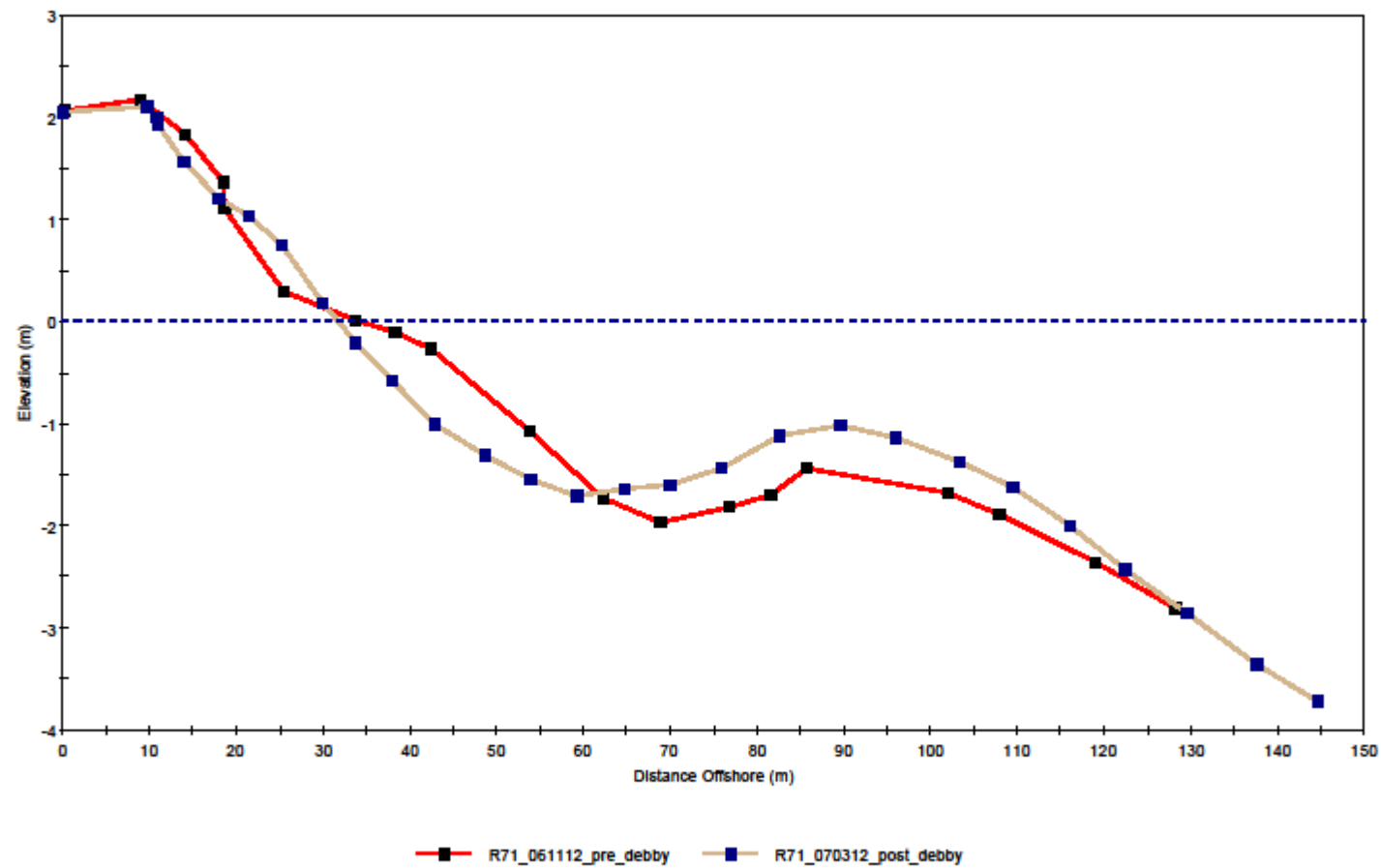
R70



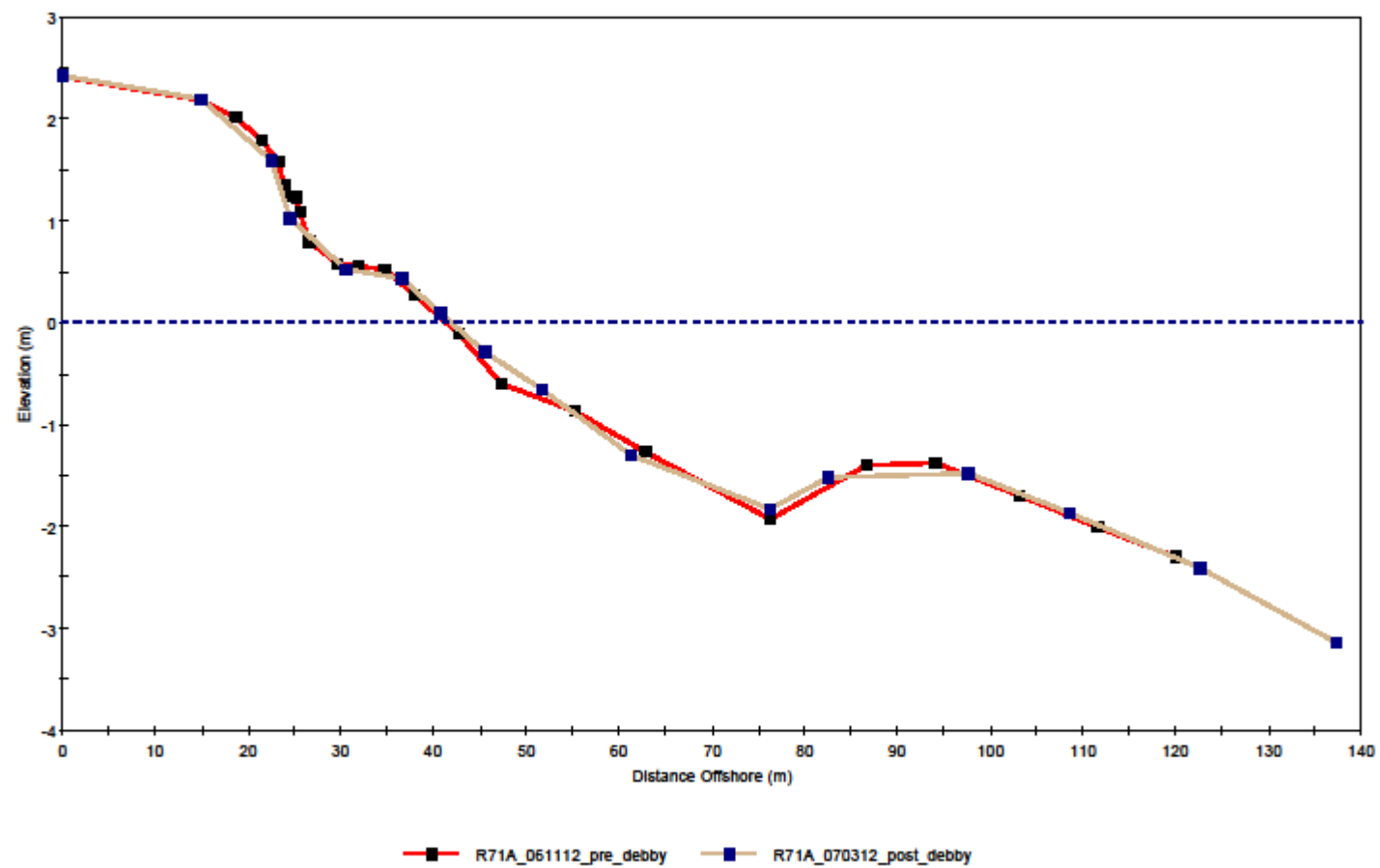
R70A



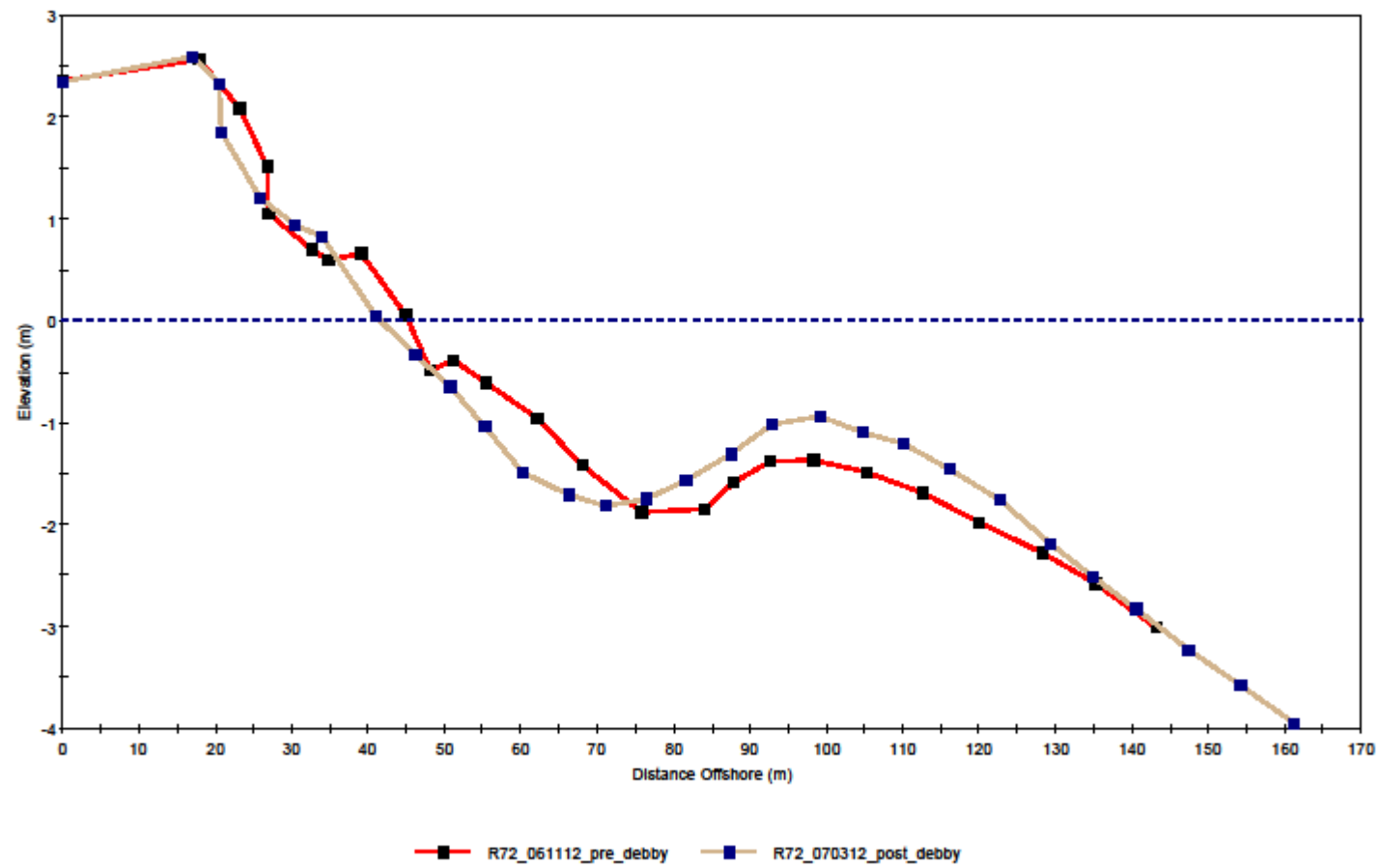
R71



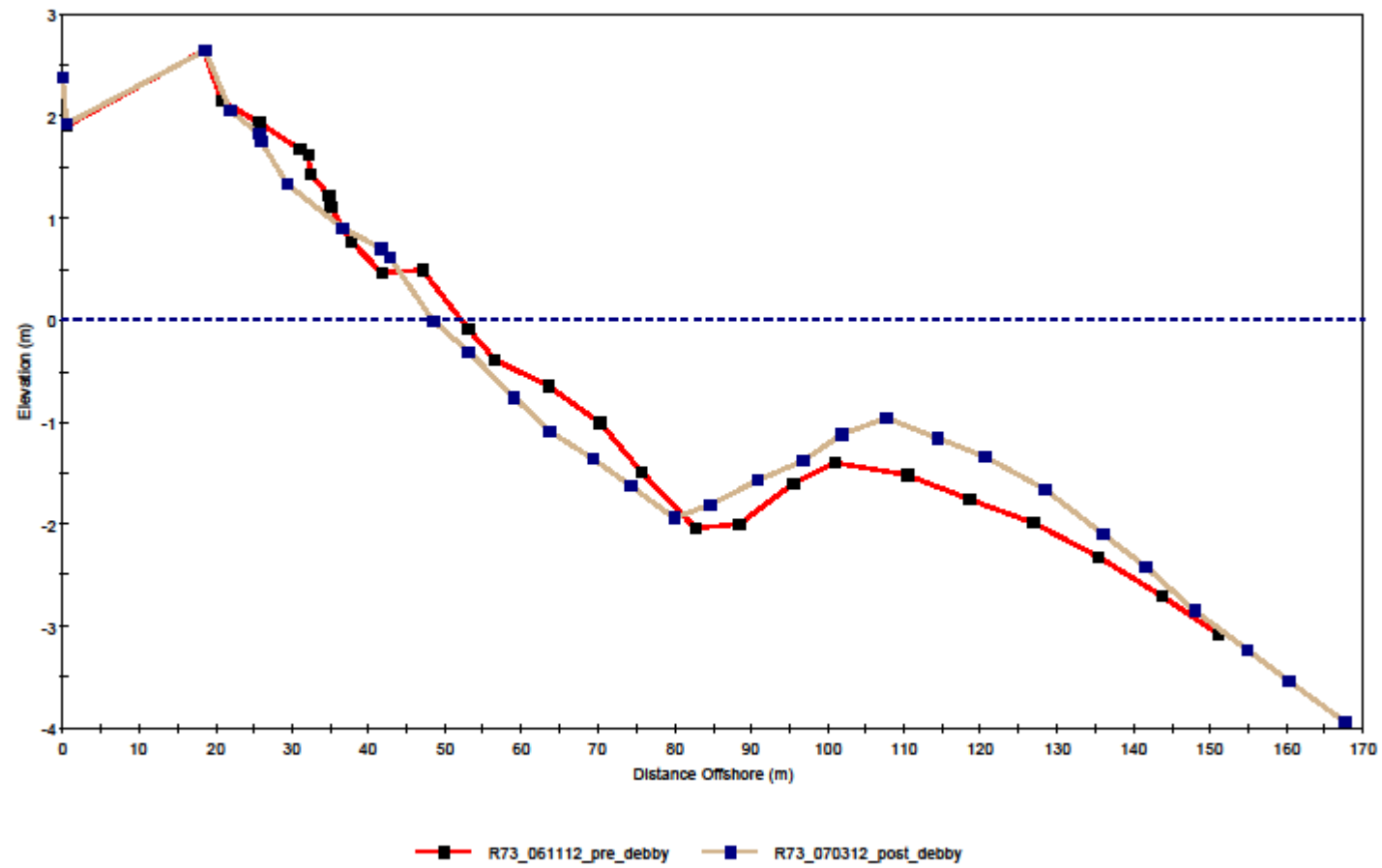
R71A



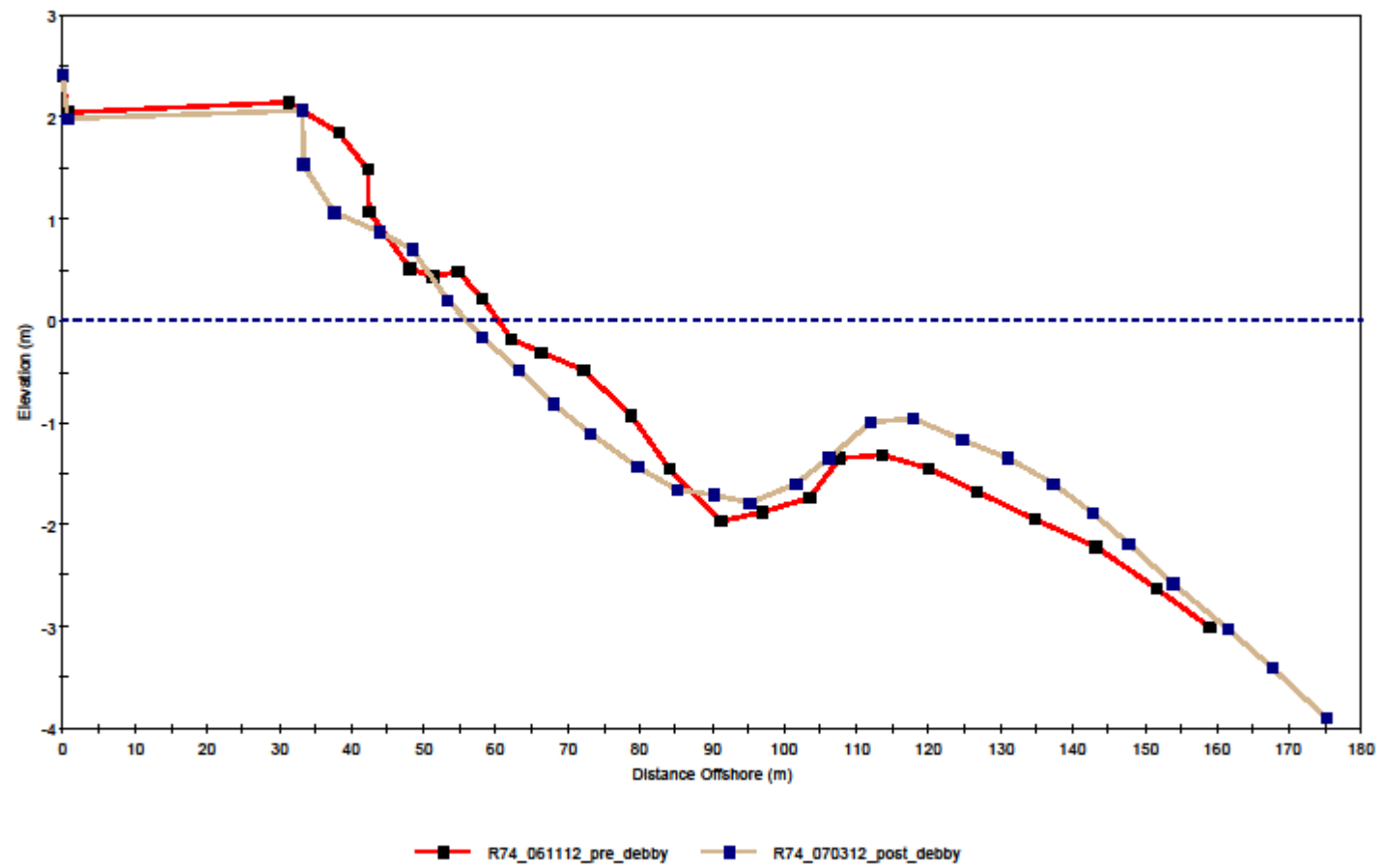
R72



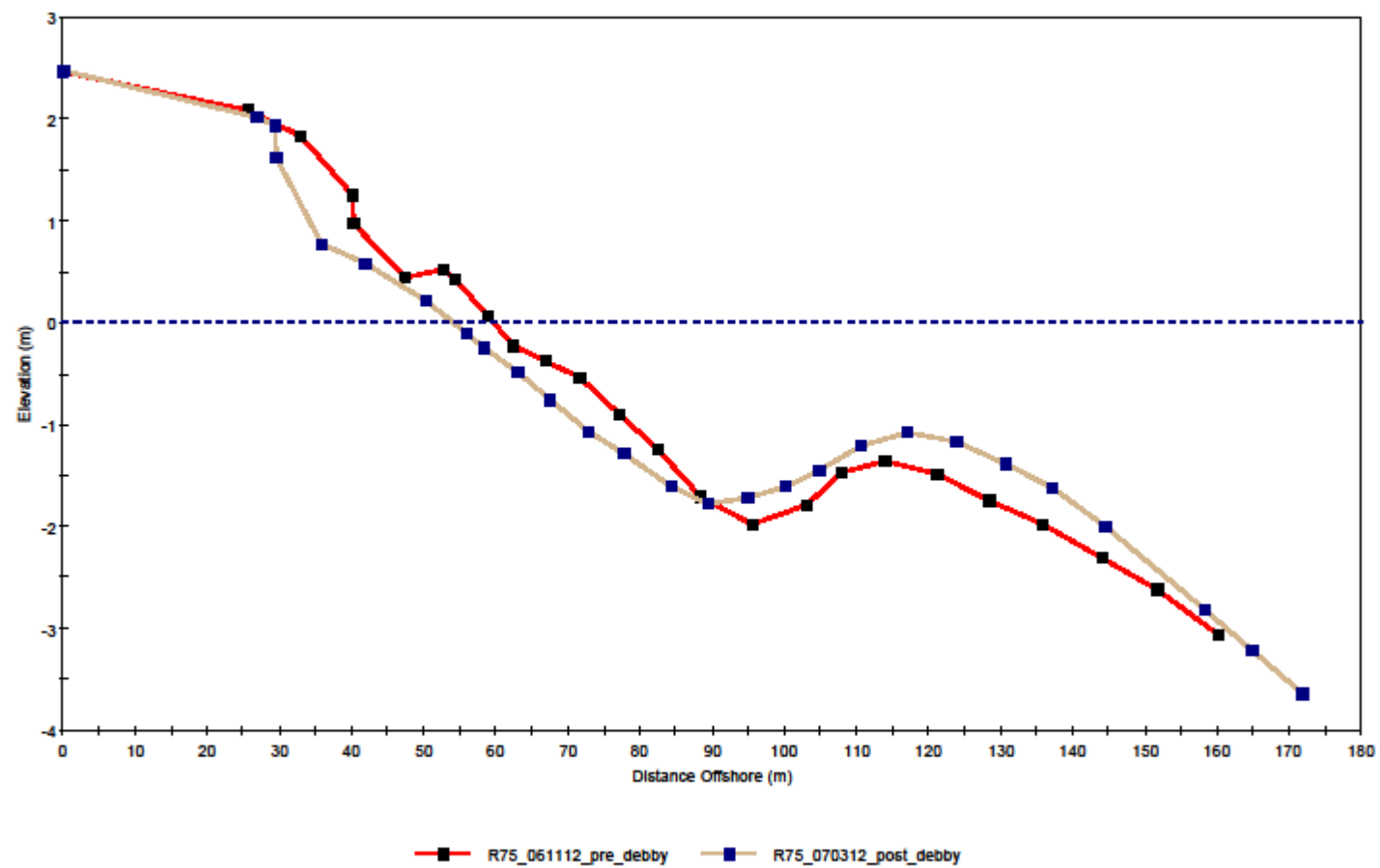
R73



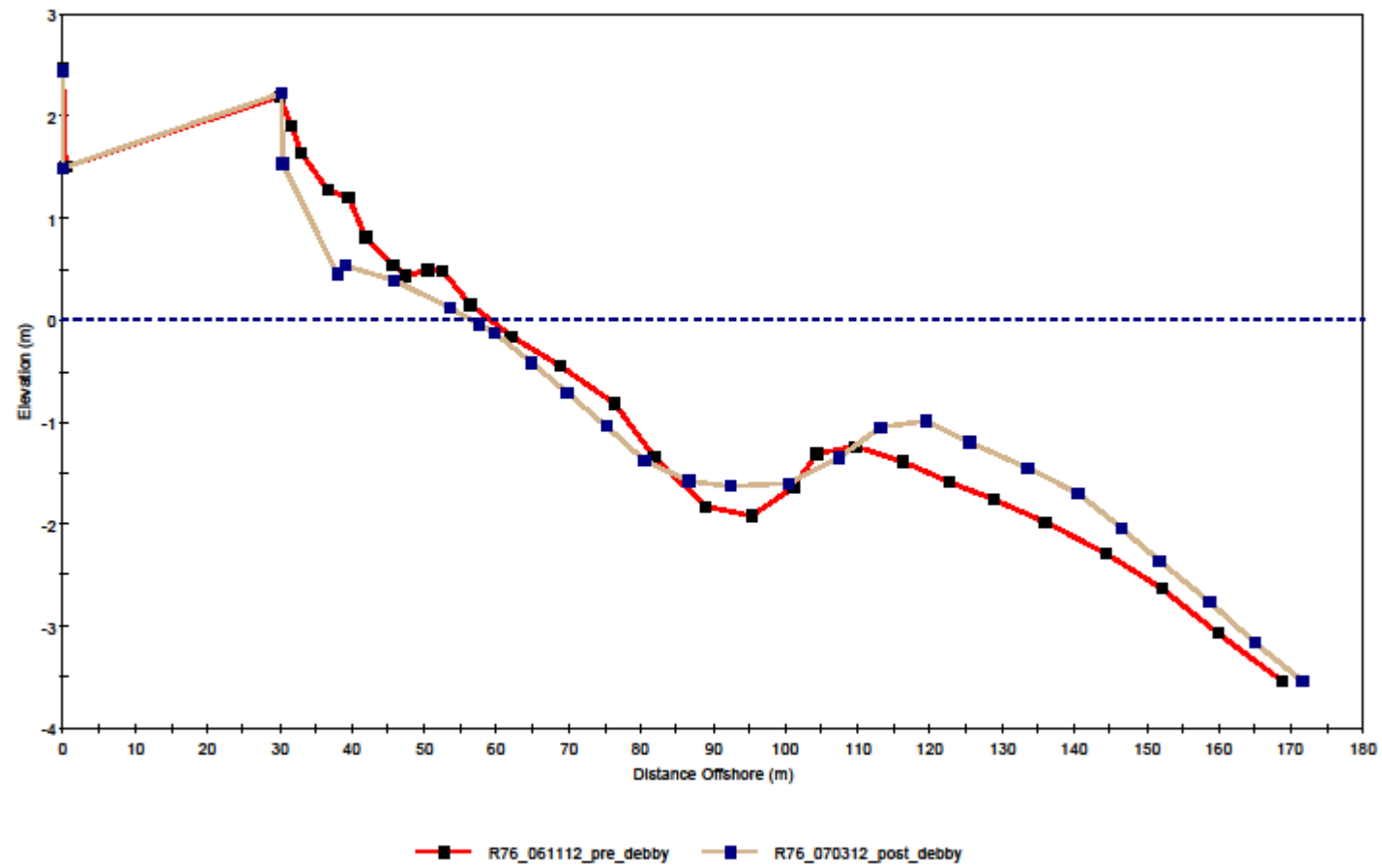
R74



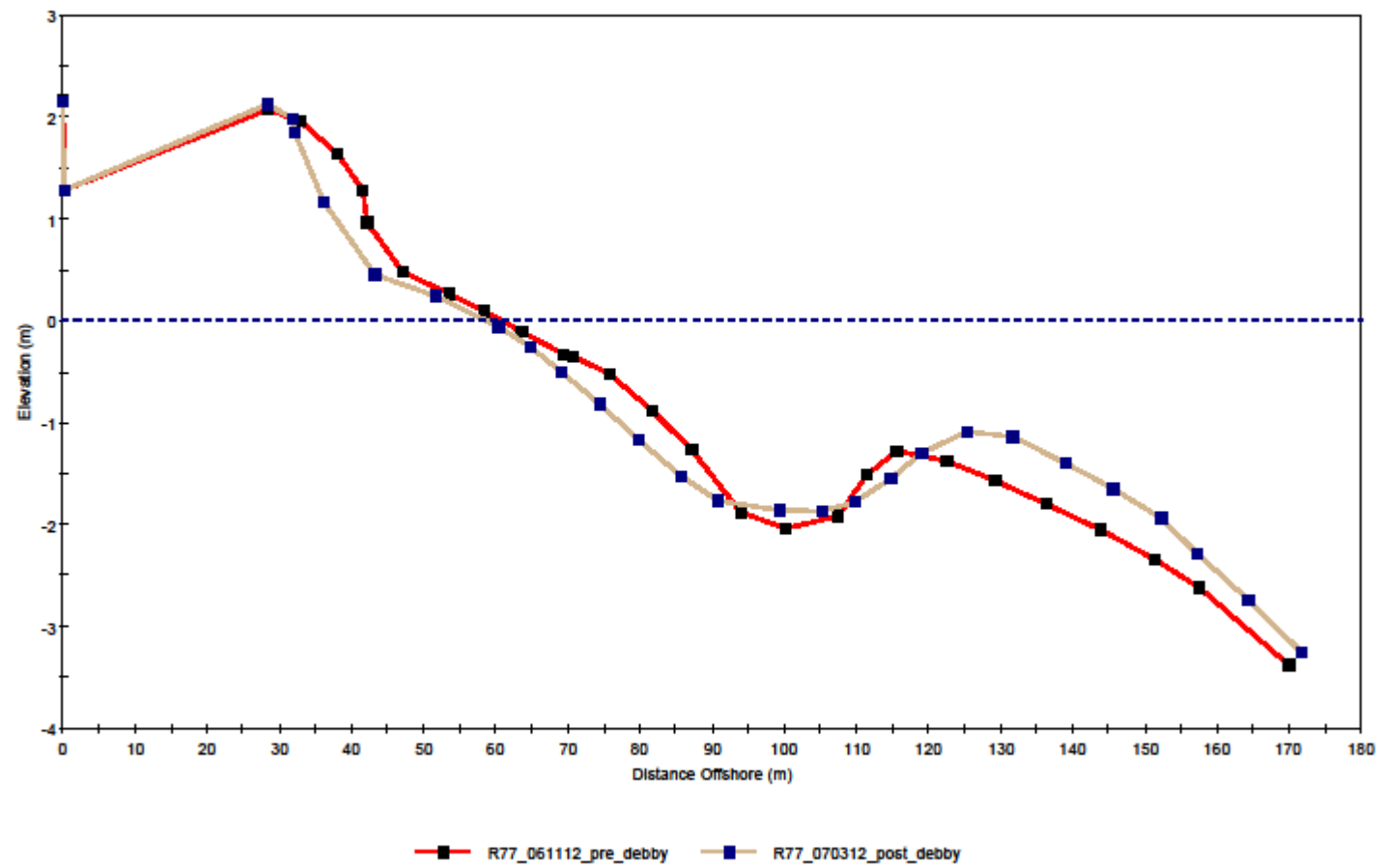
R75



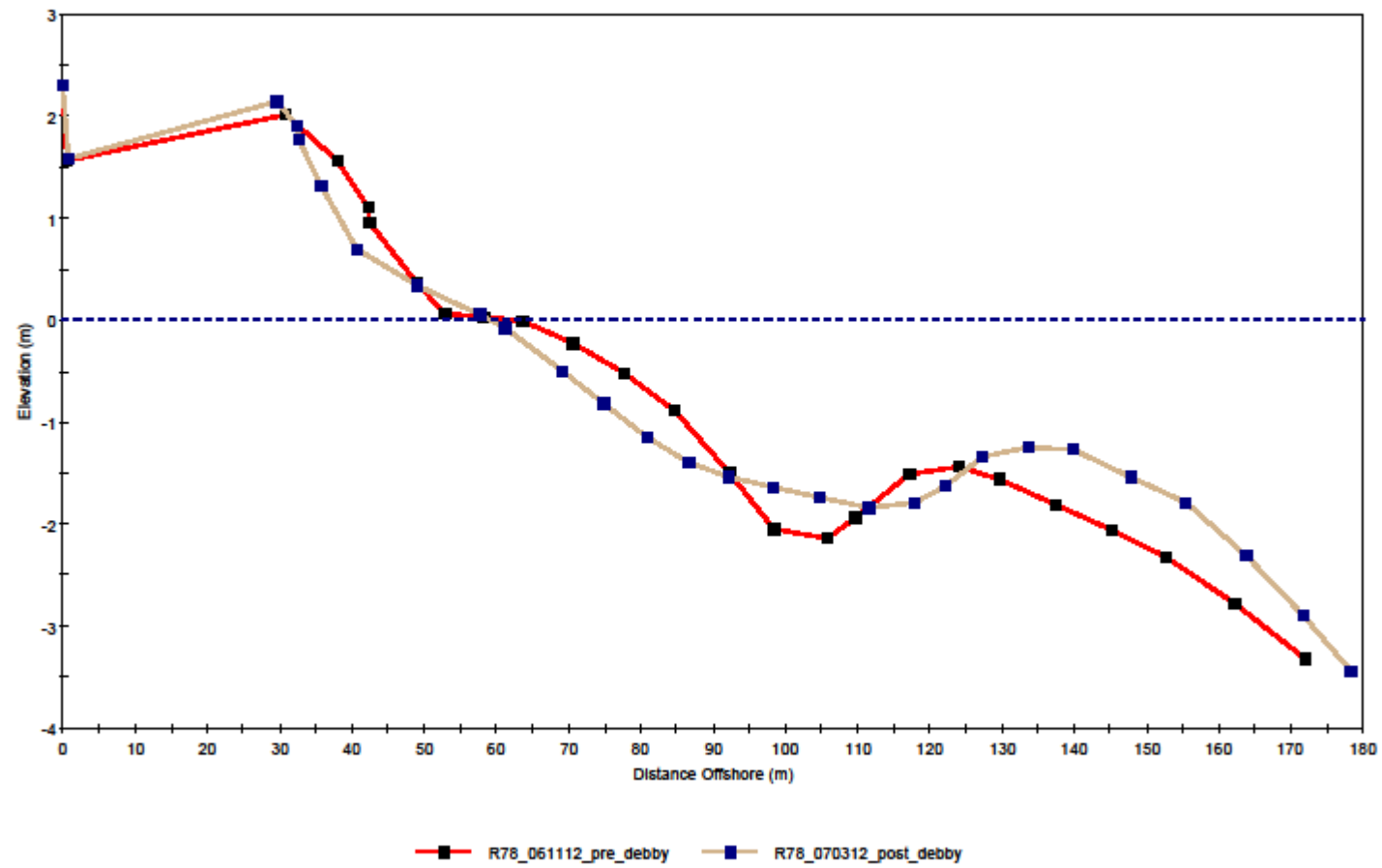
R76



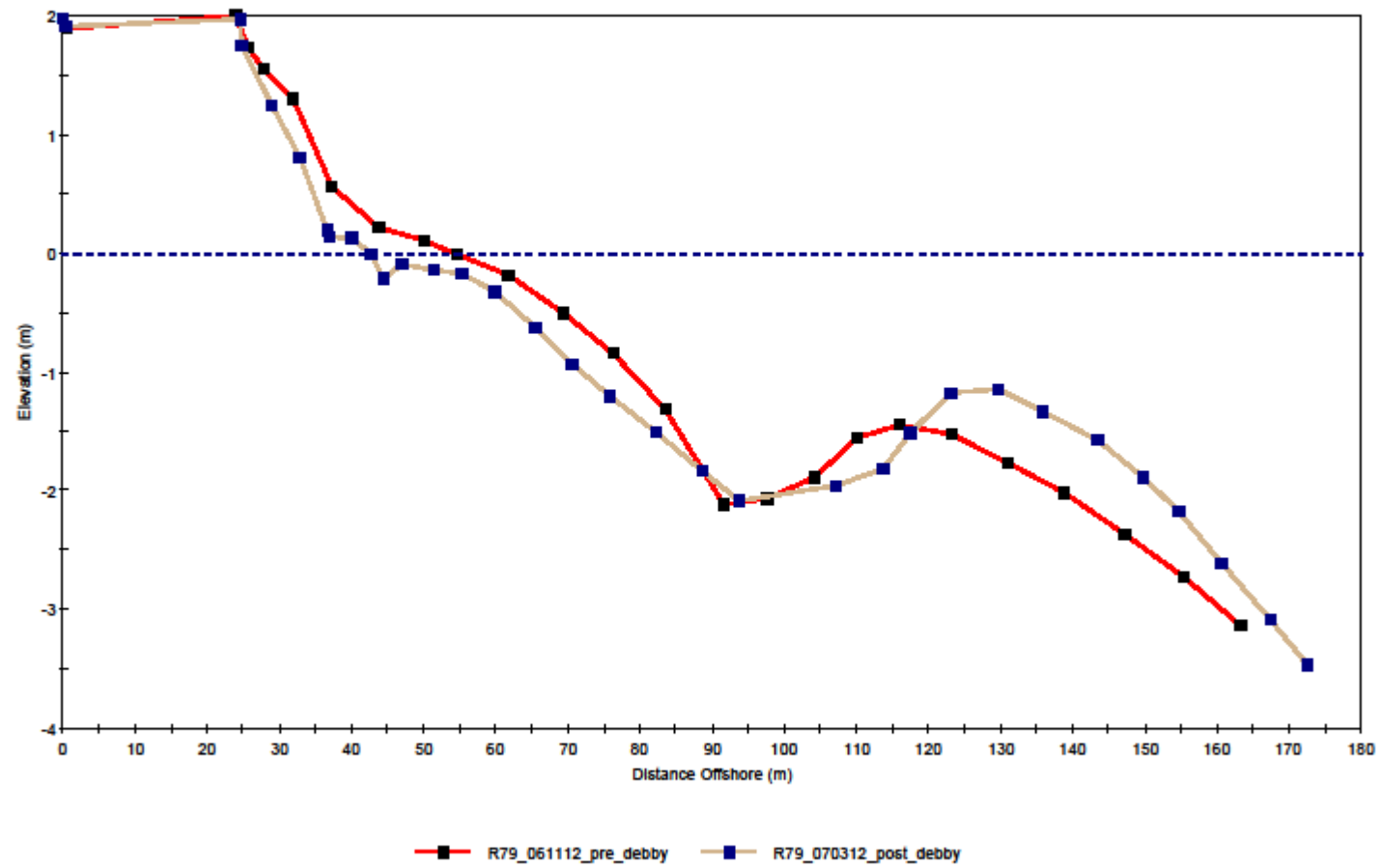
R77



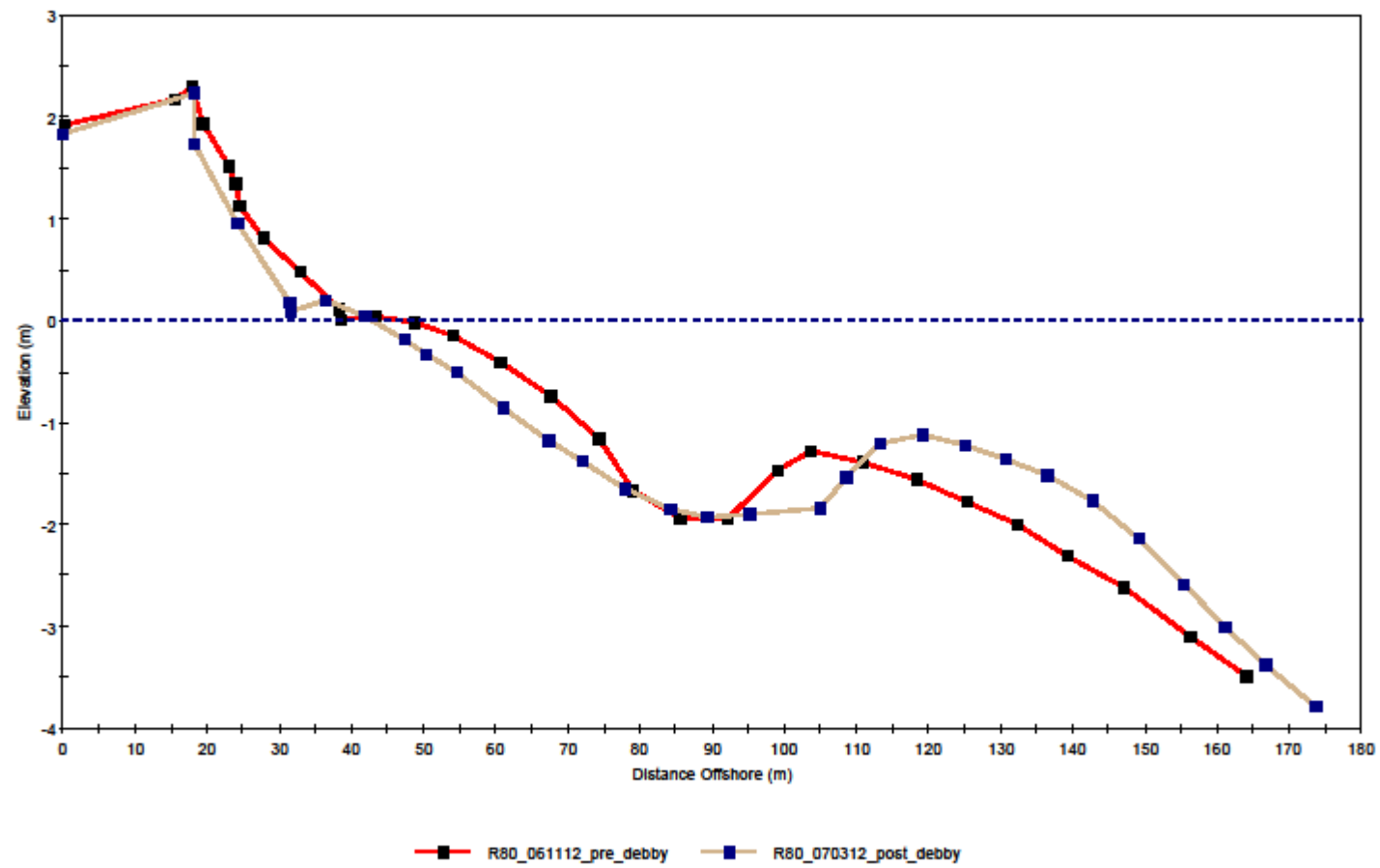
R78



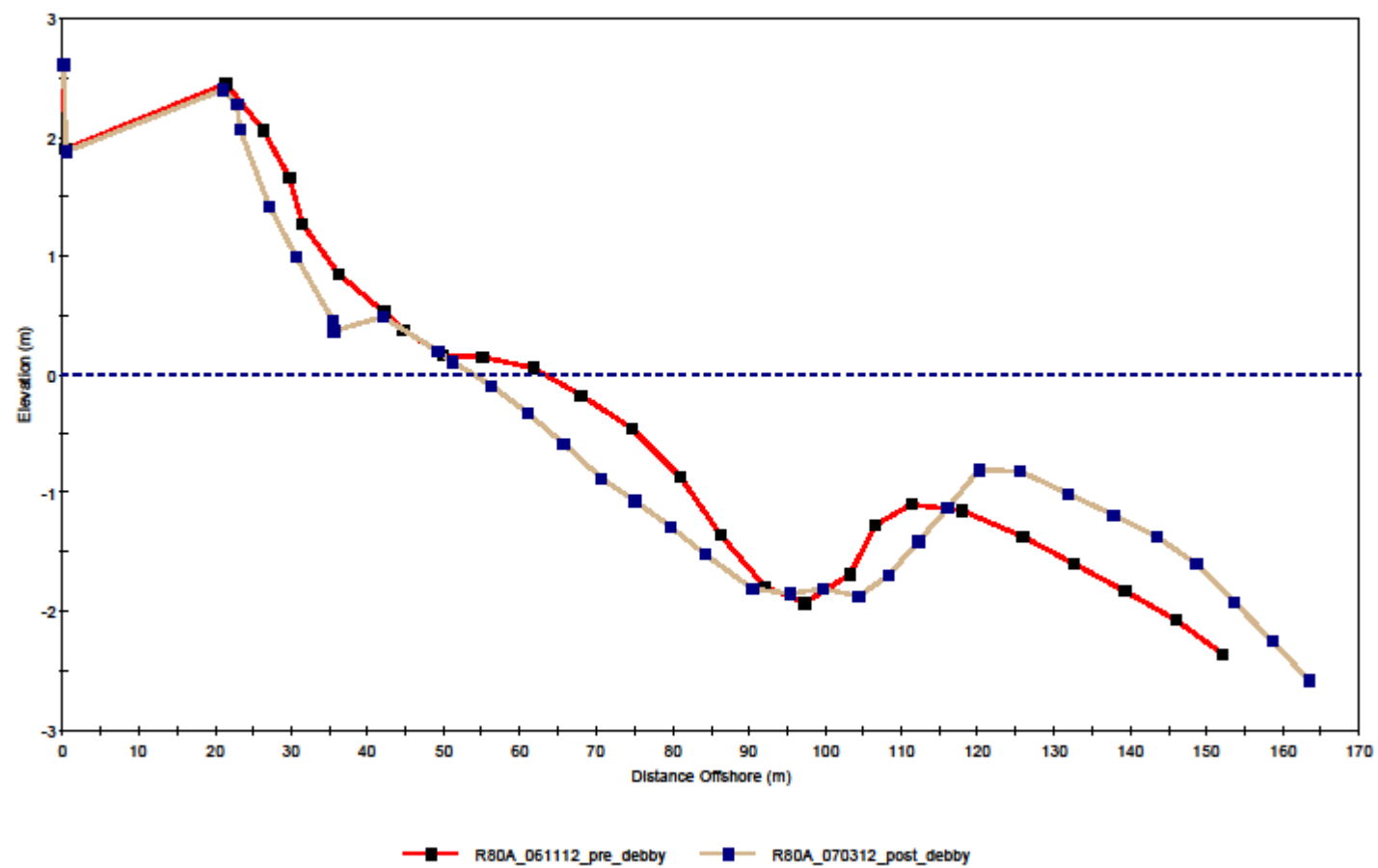
R79



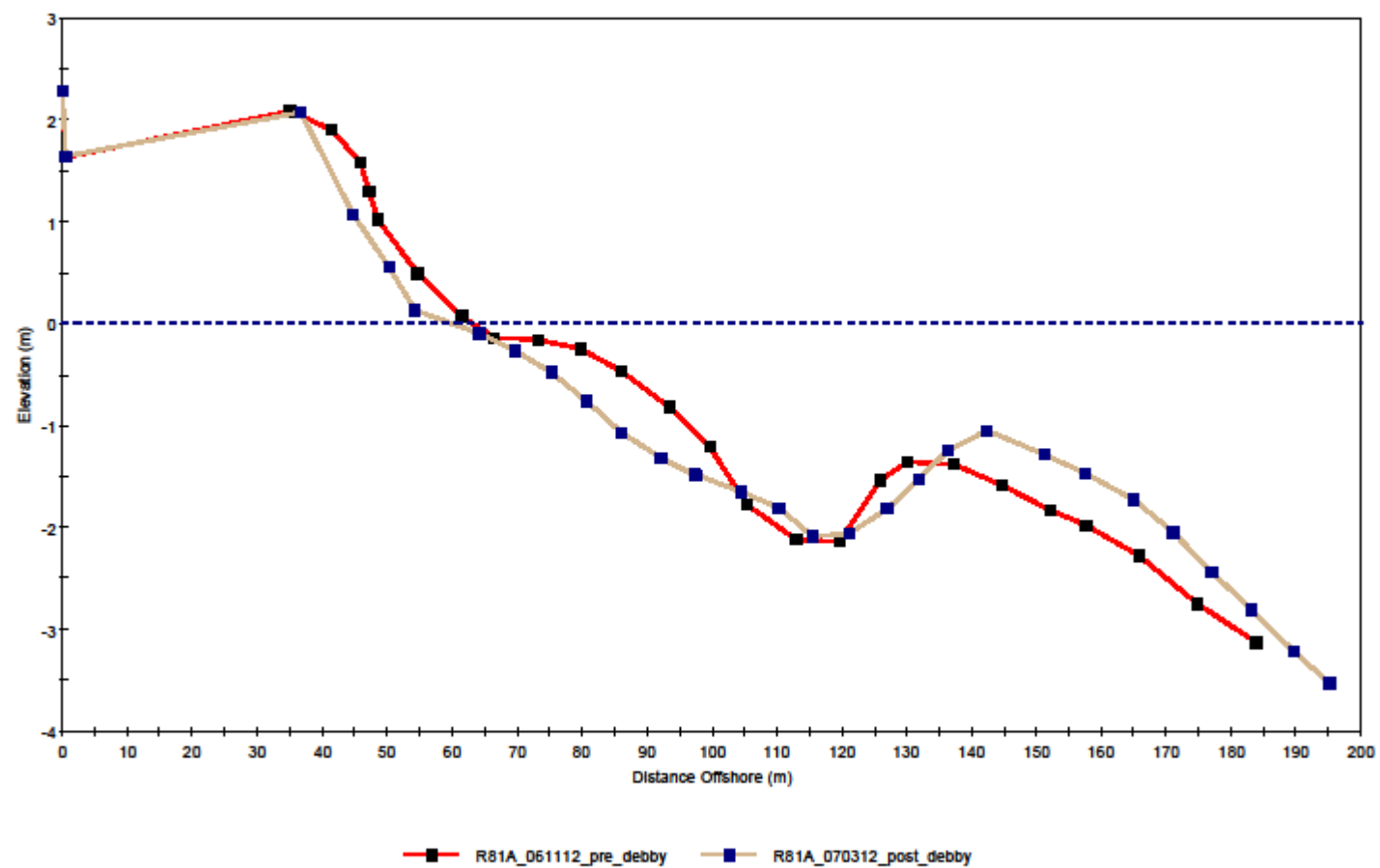
R80



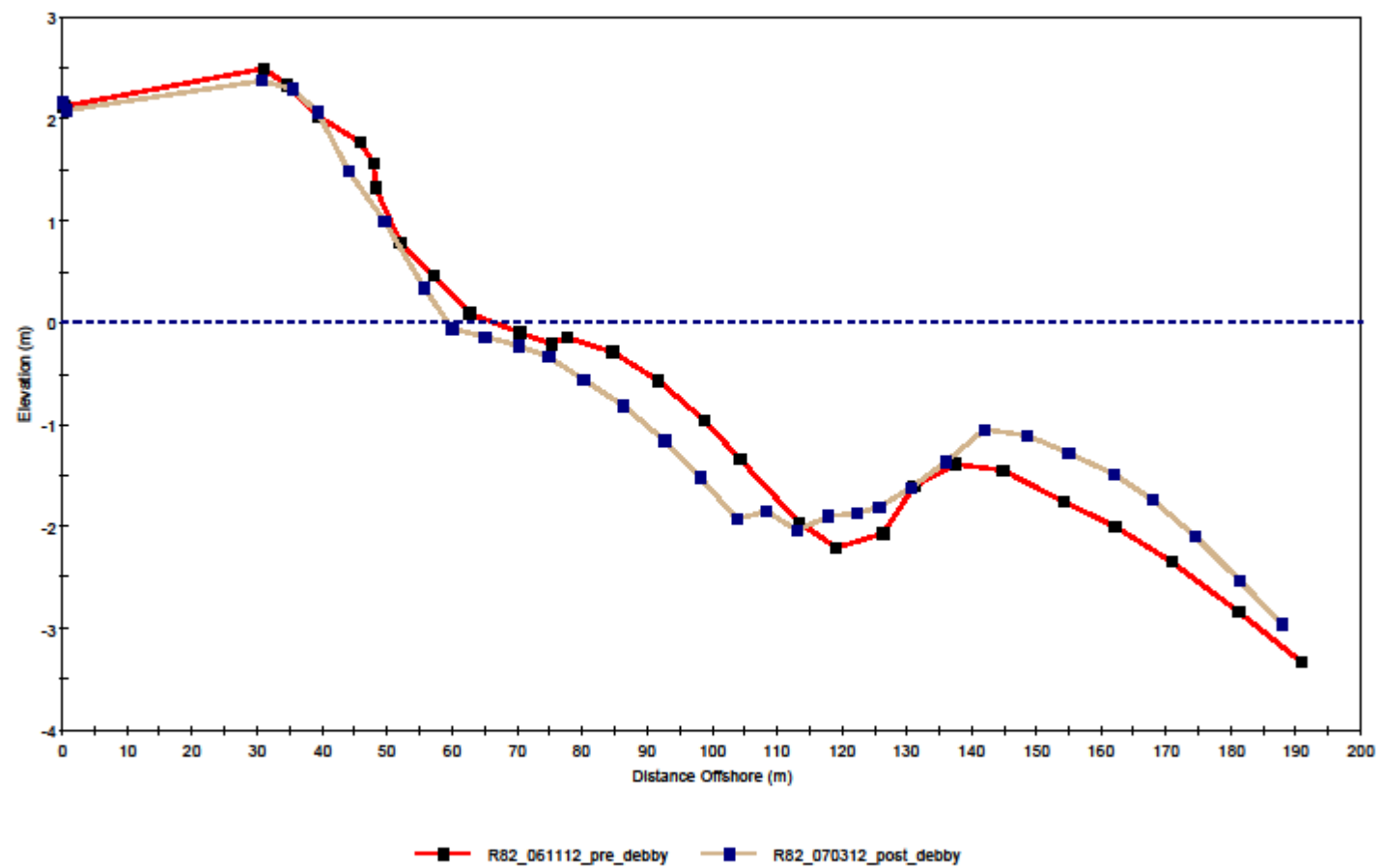
R80A



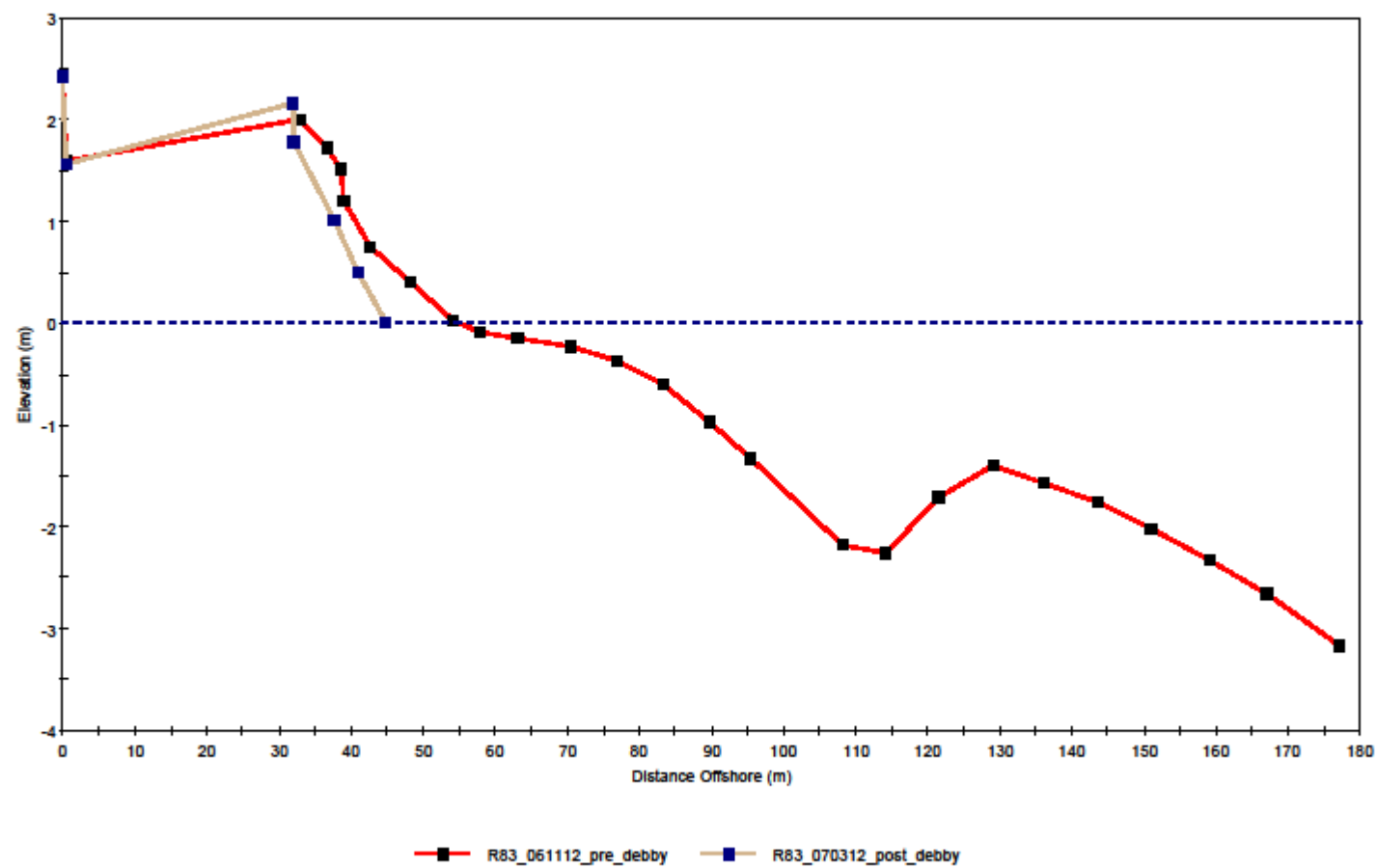
R81A



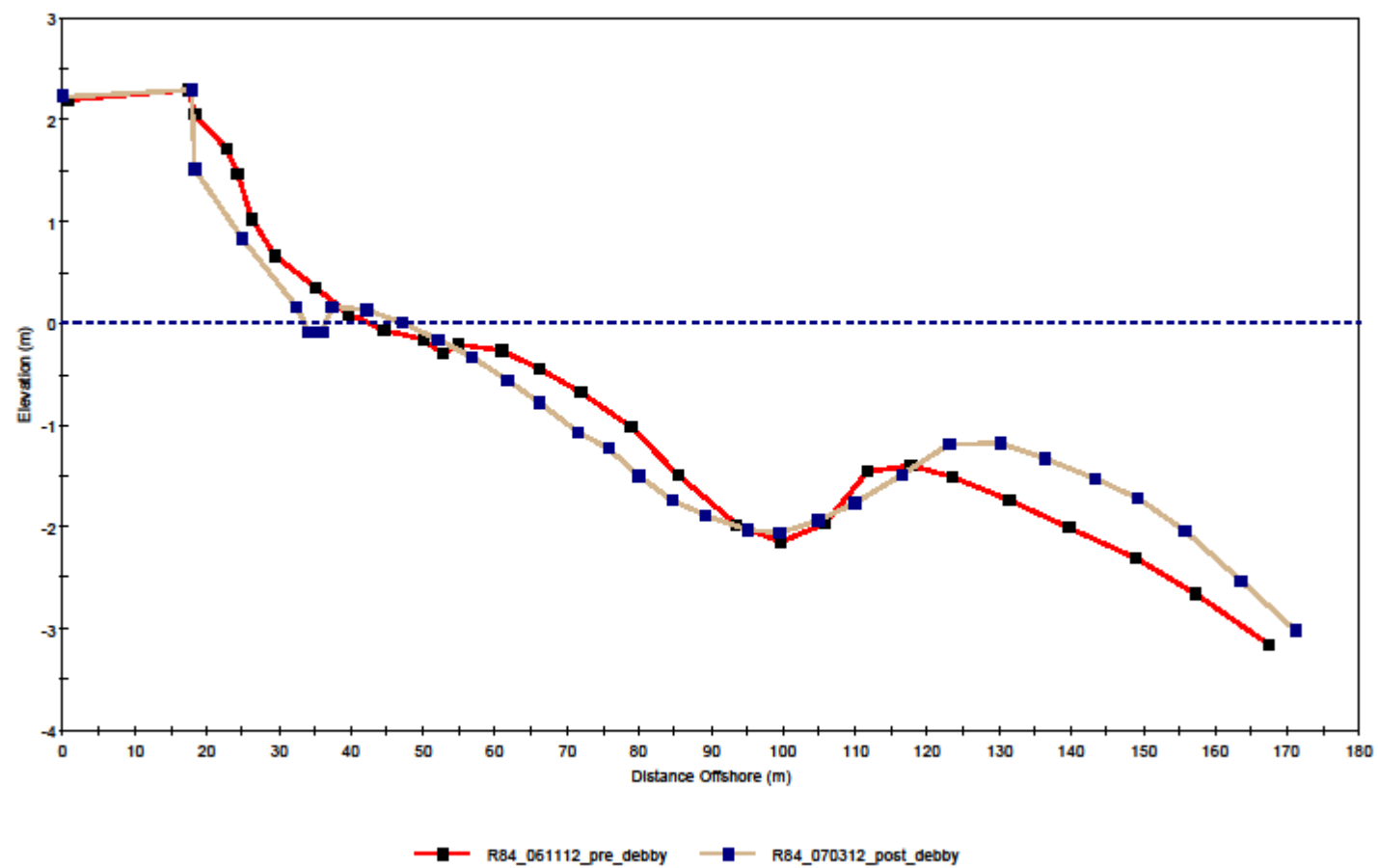
R82



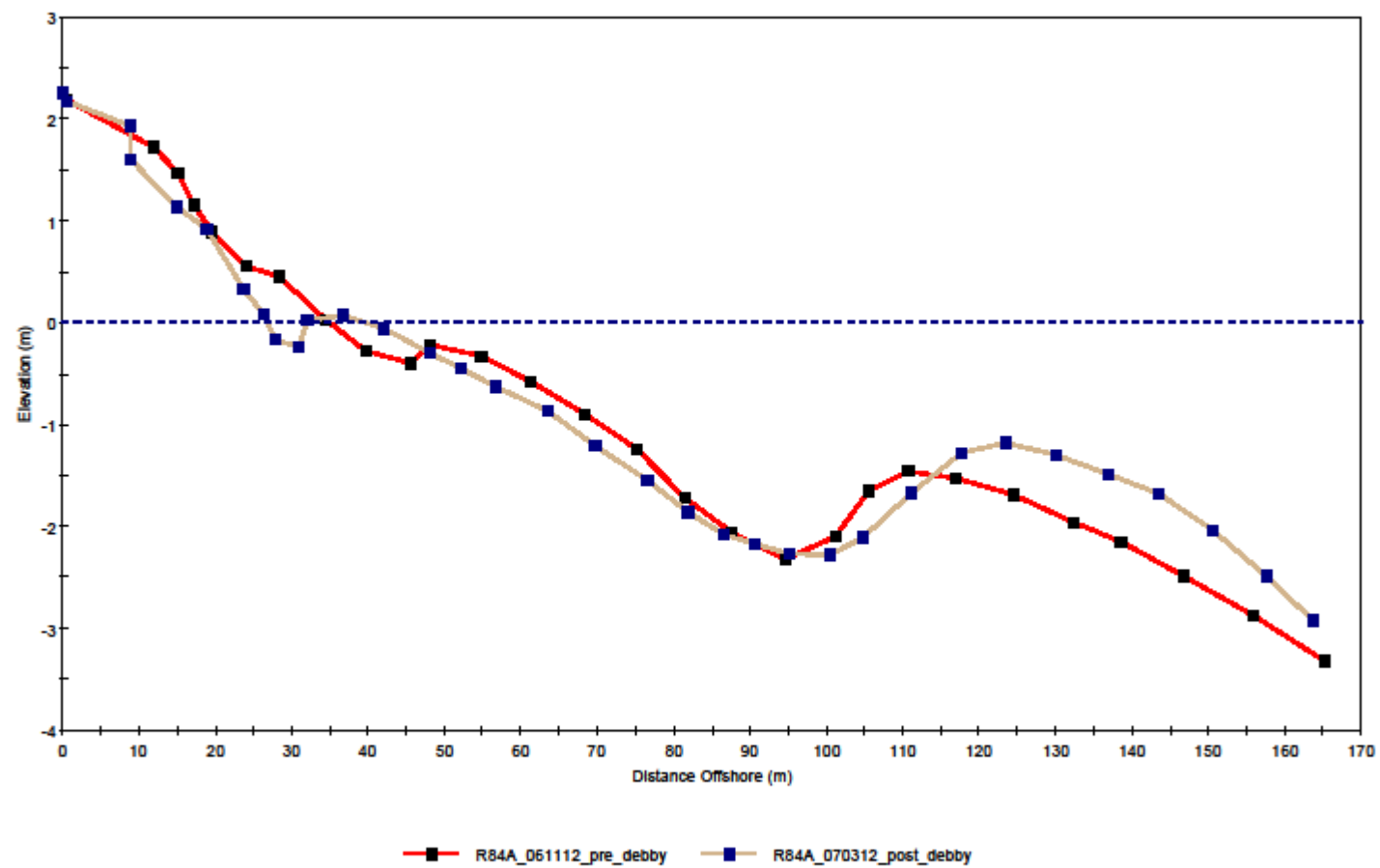
R83



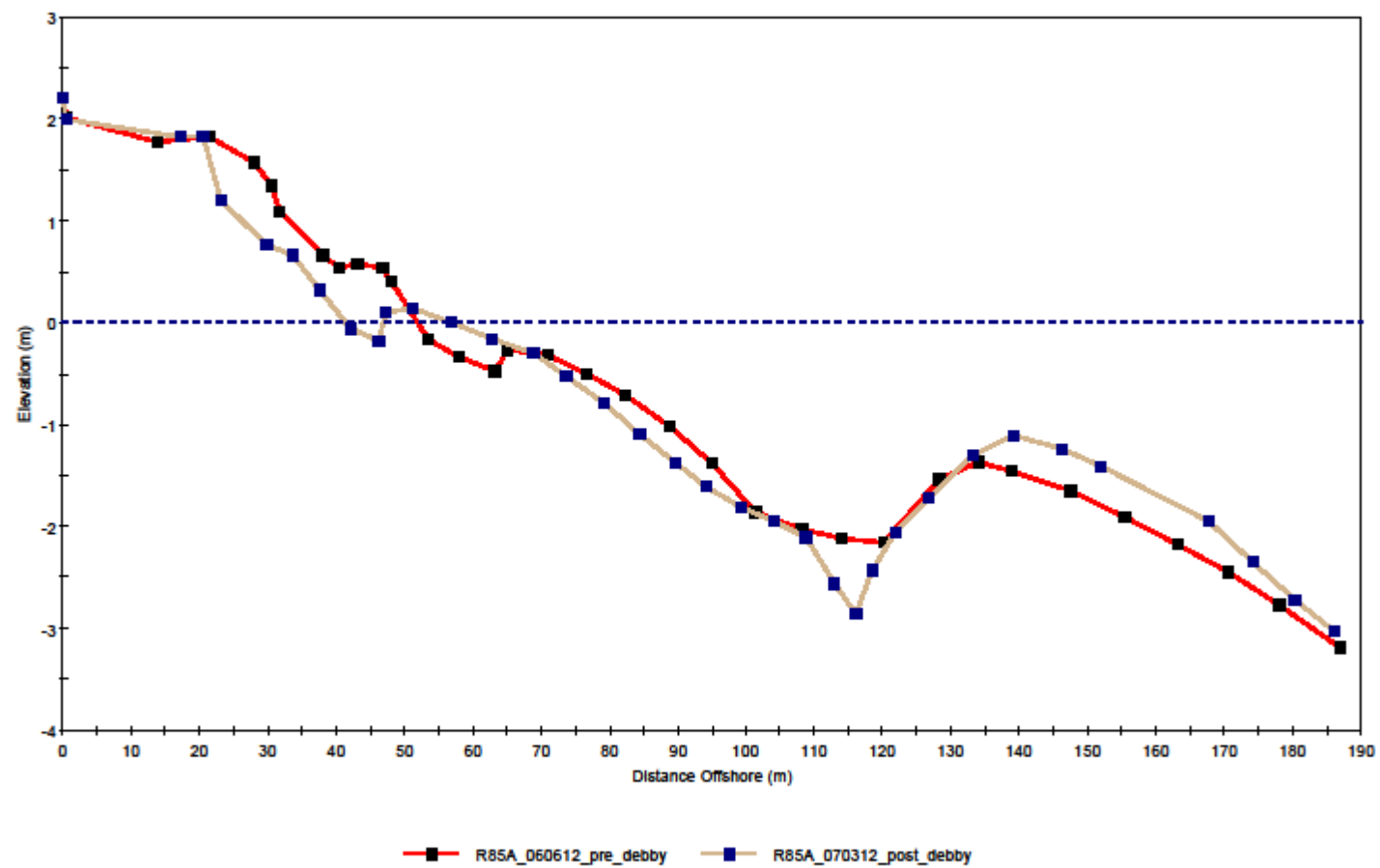
R84



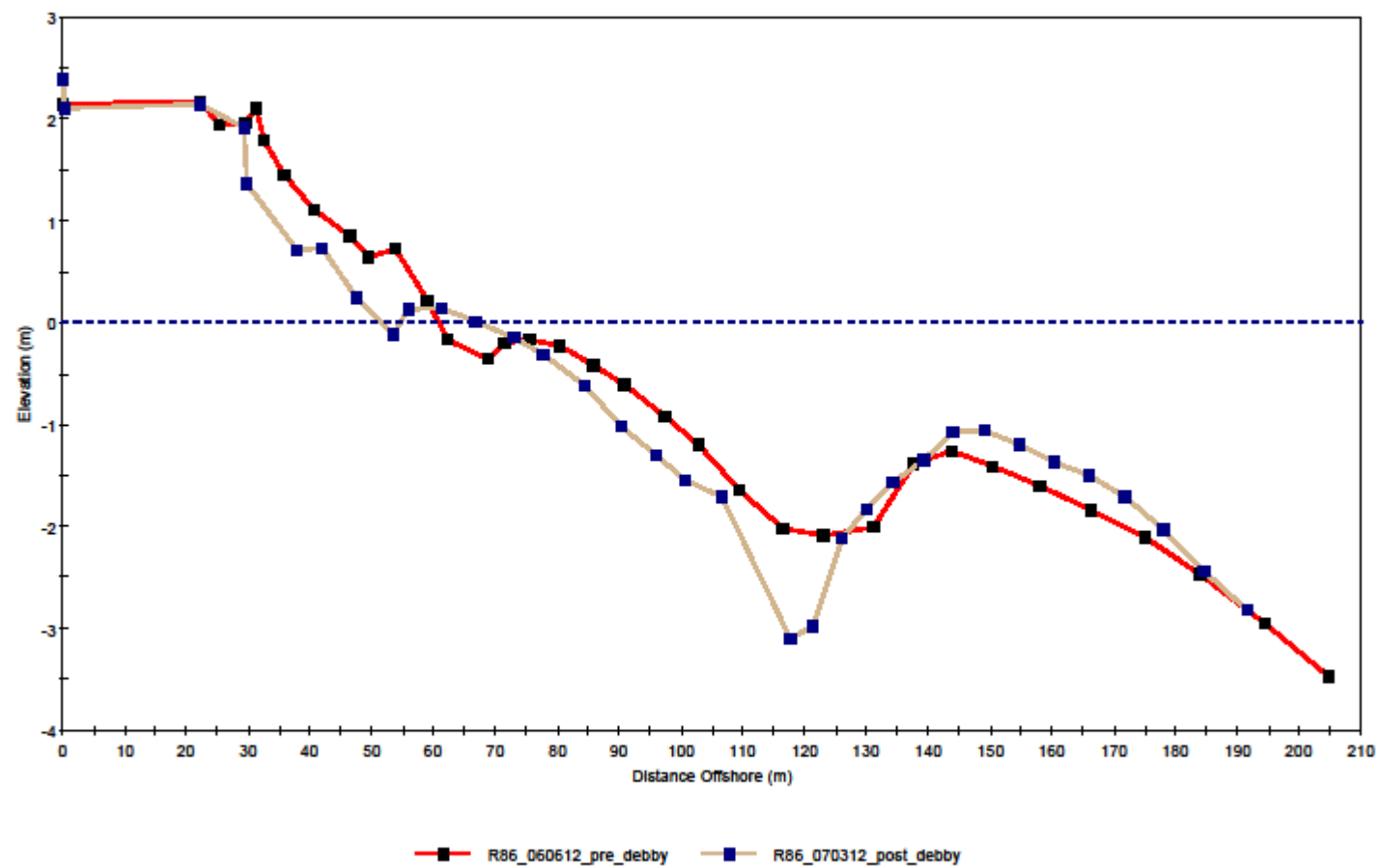
R84A



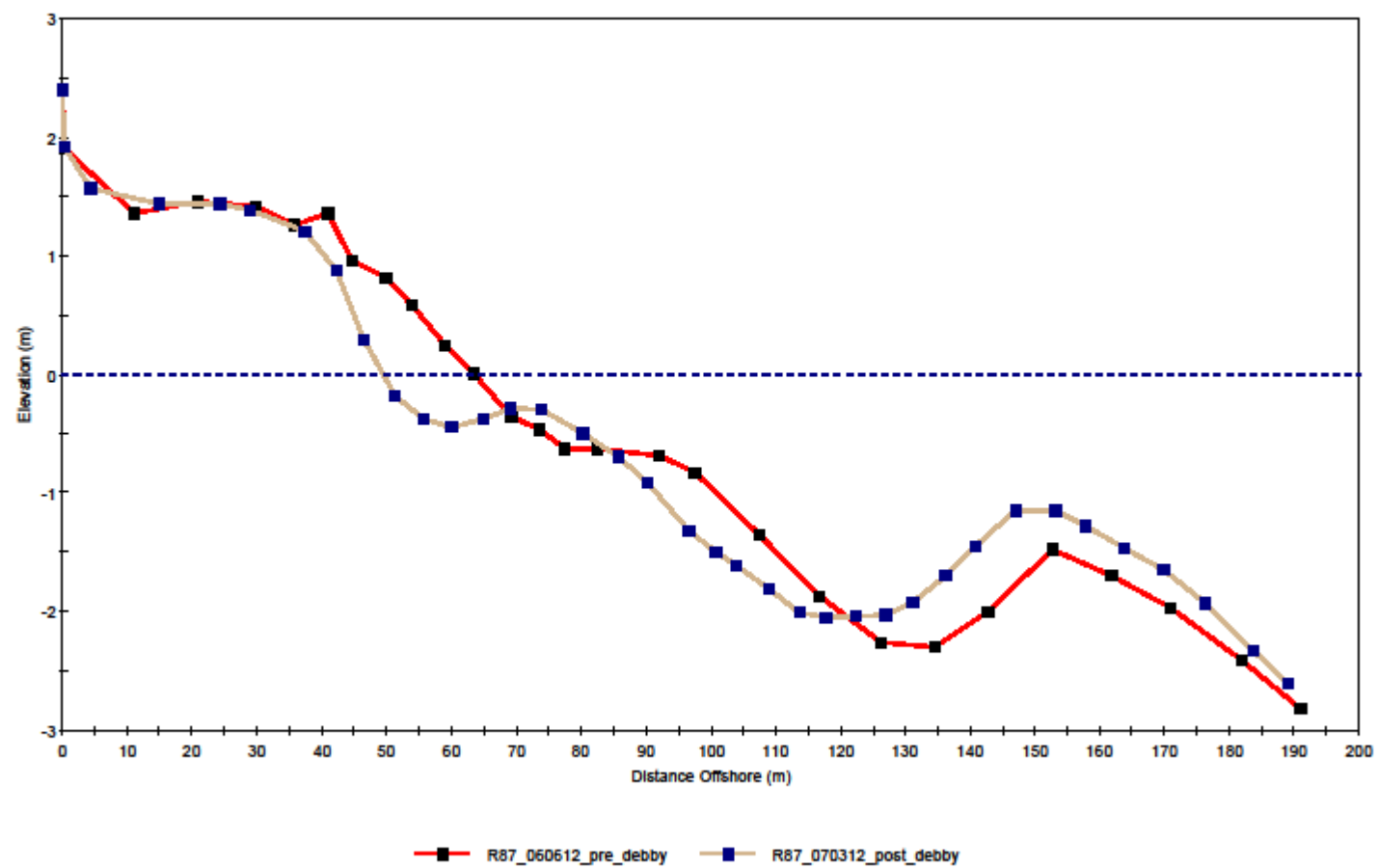
R85A



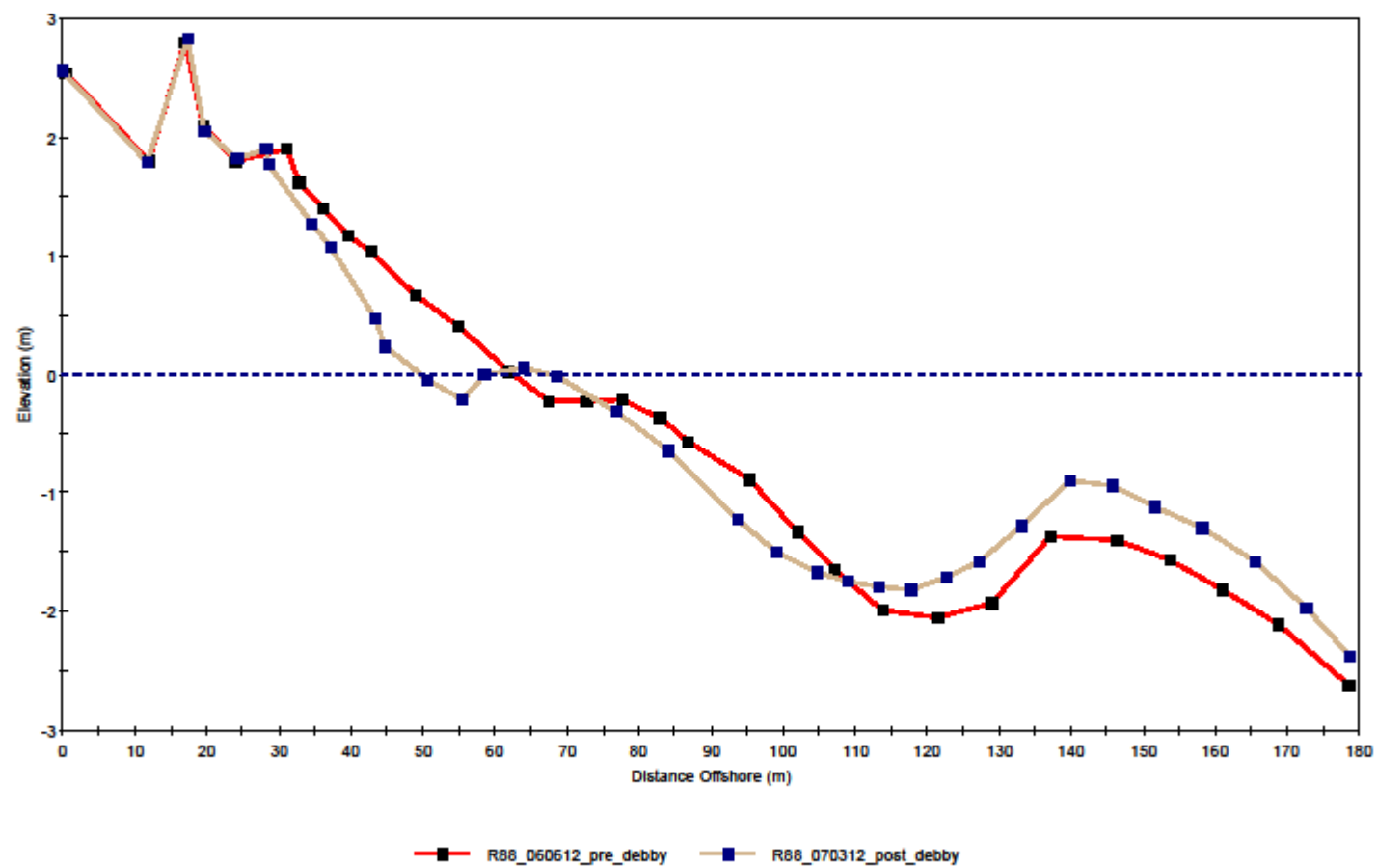
R86



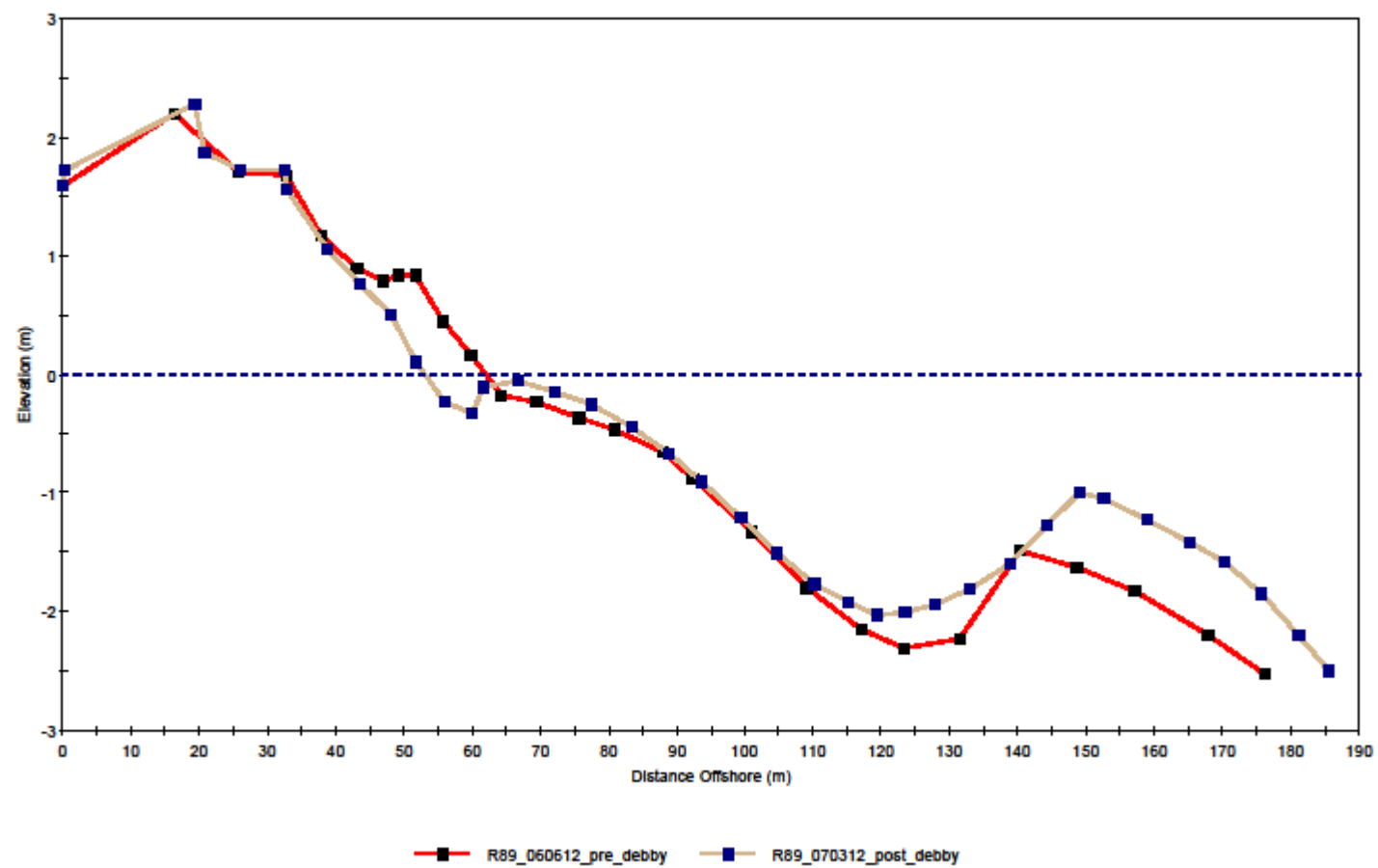
R87



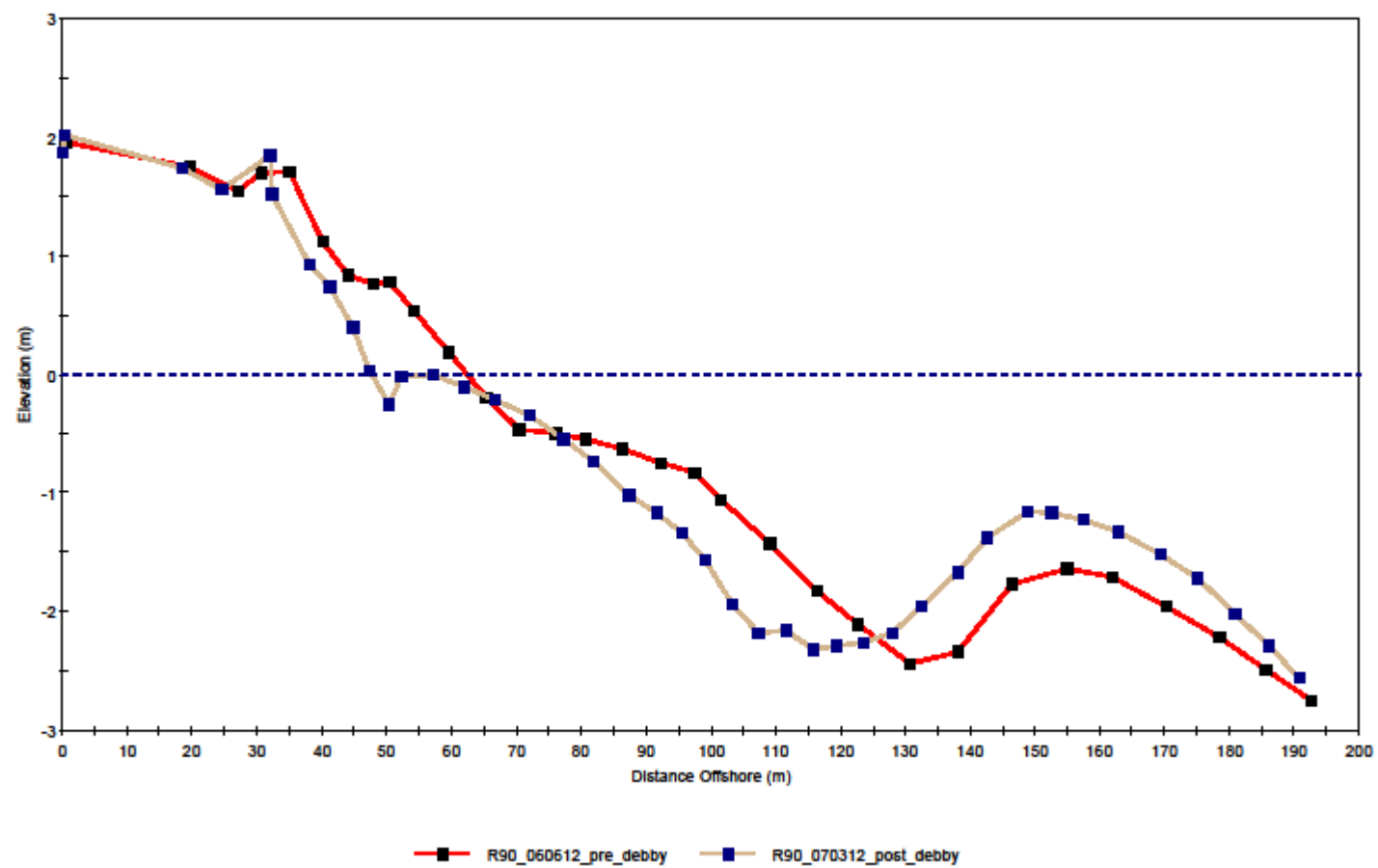
R88



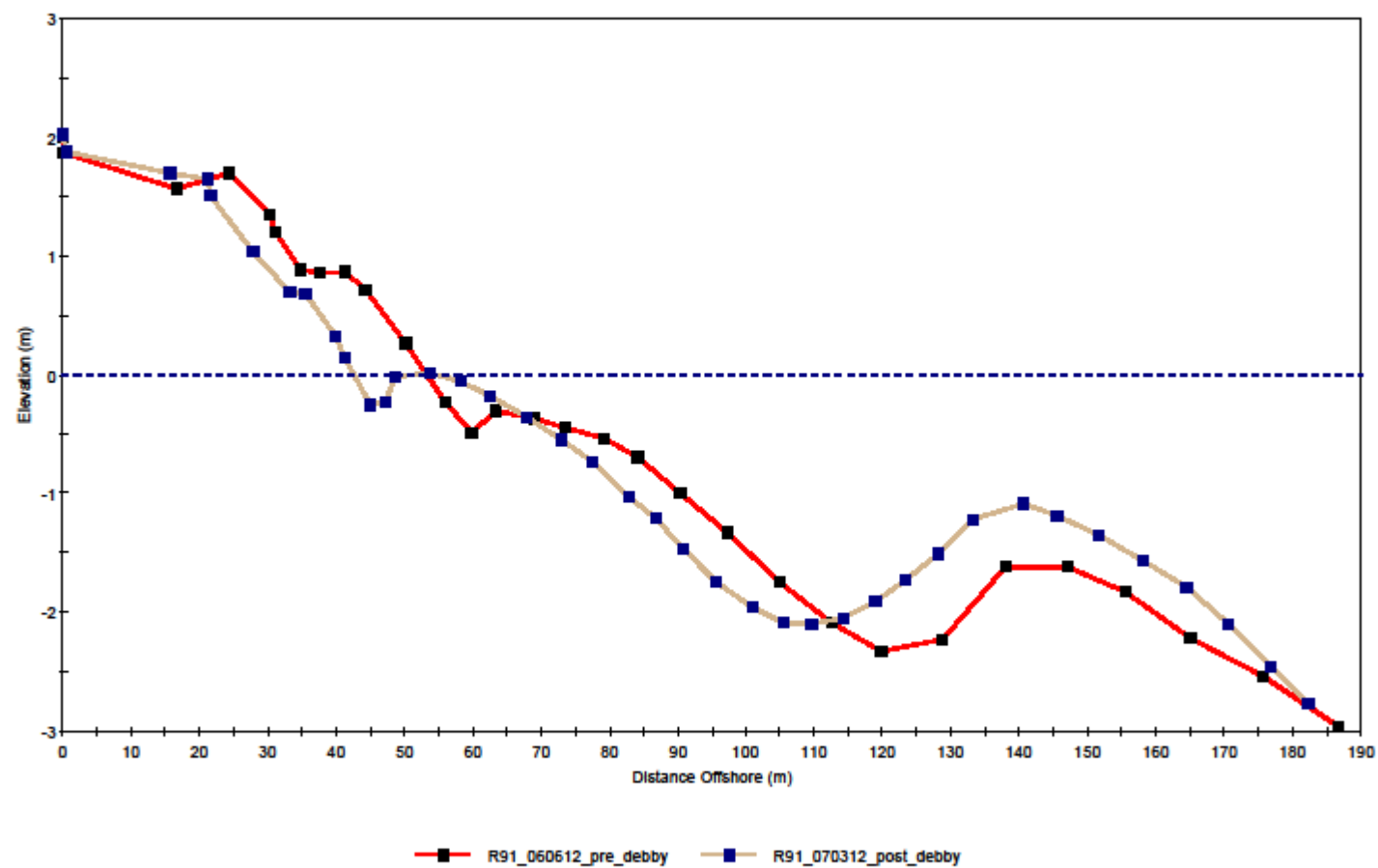
R89



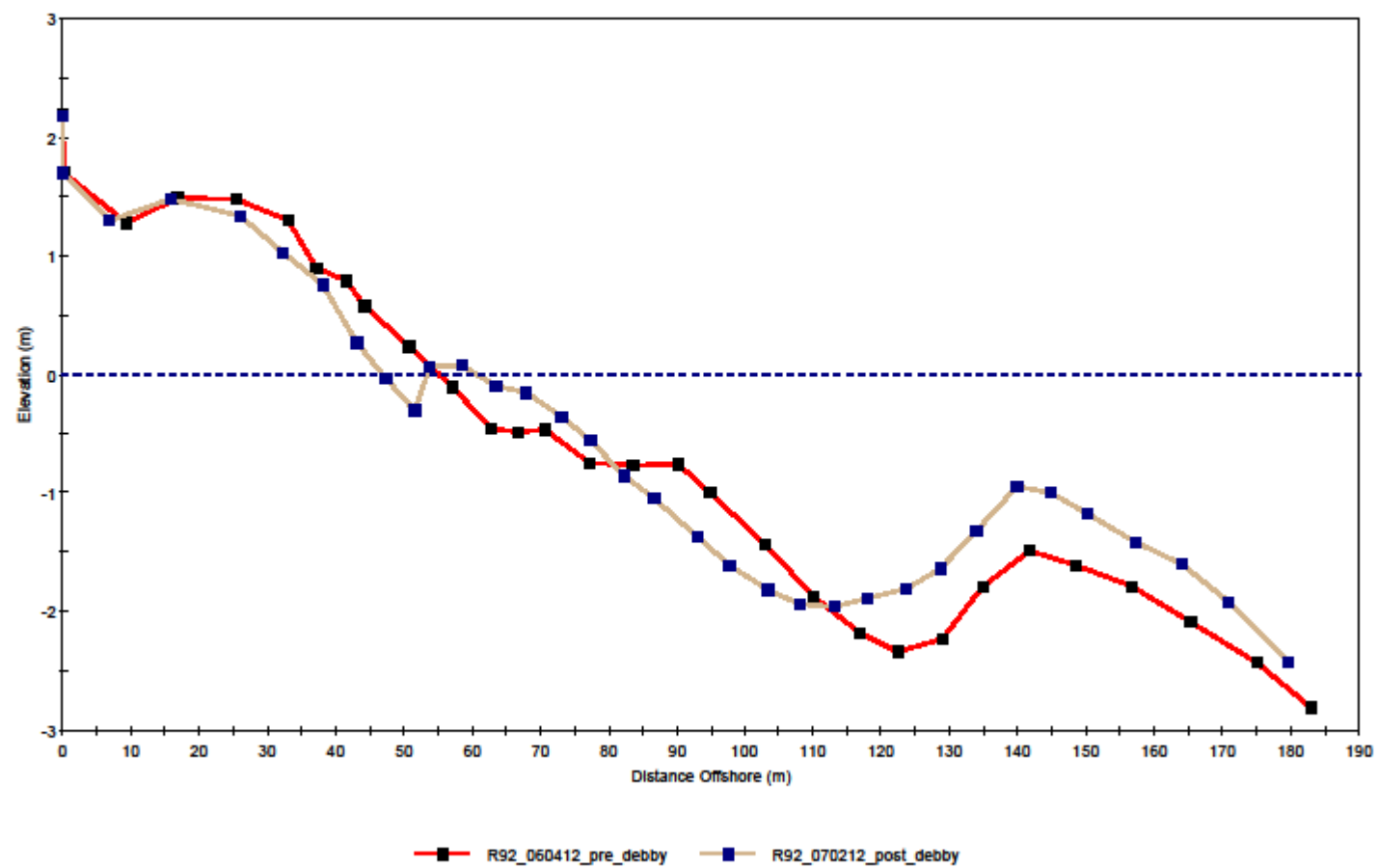
R90



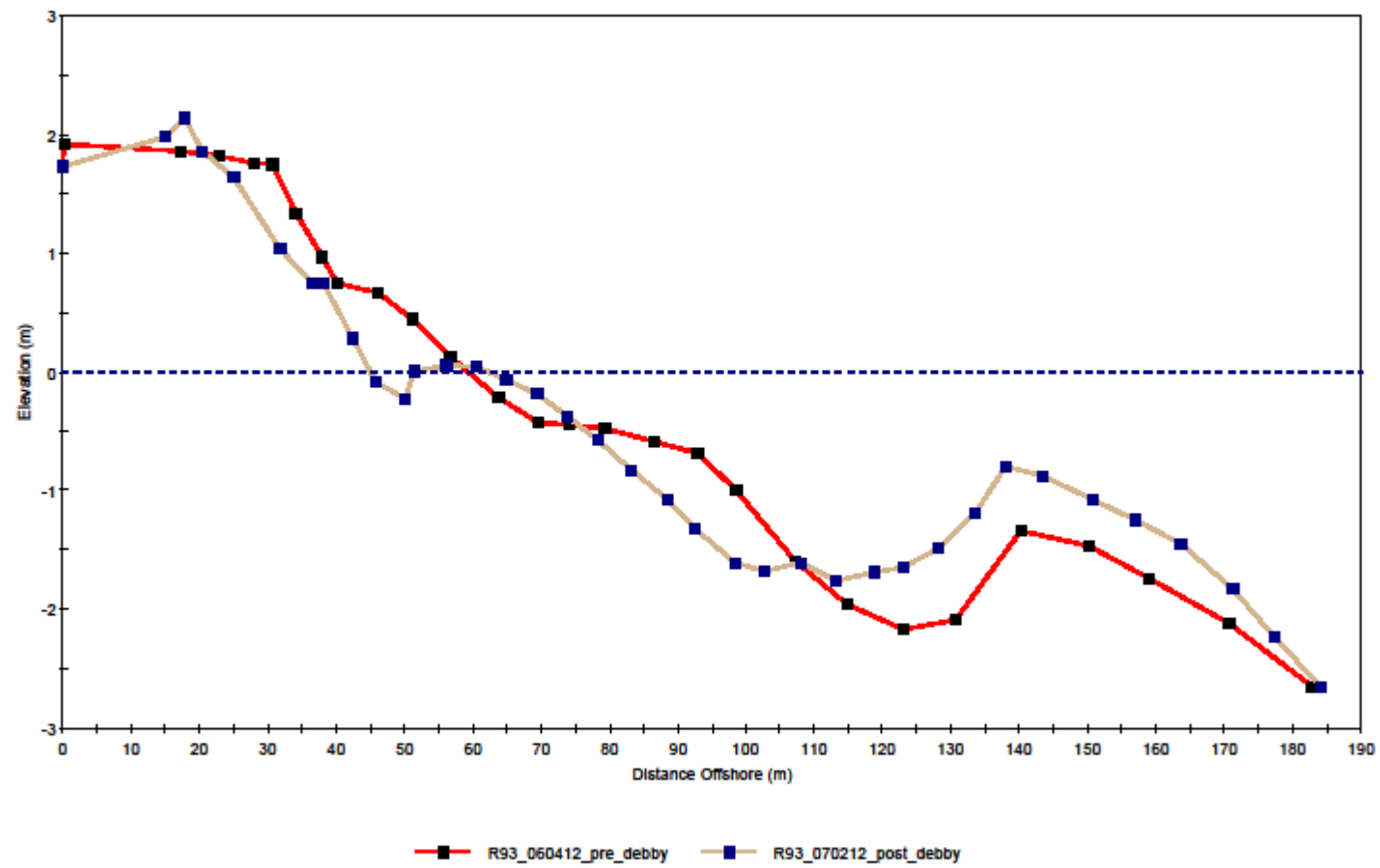
R91



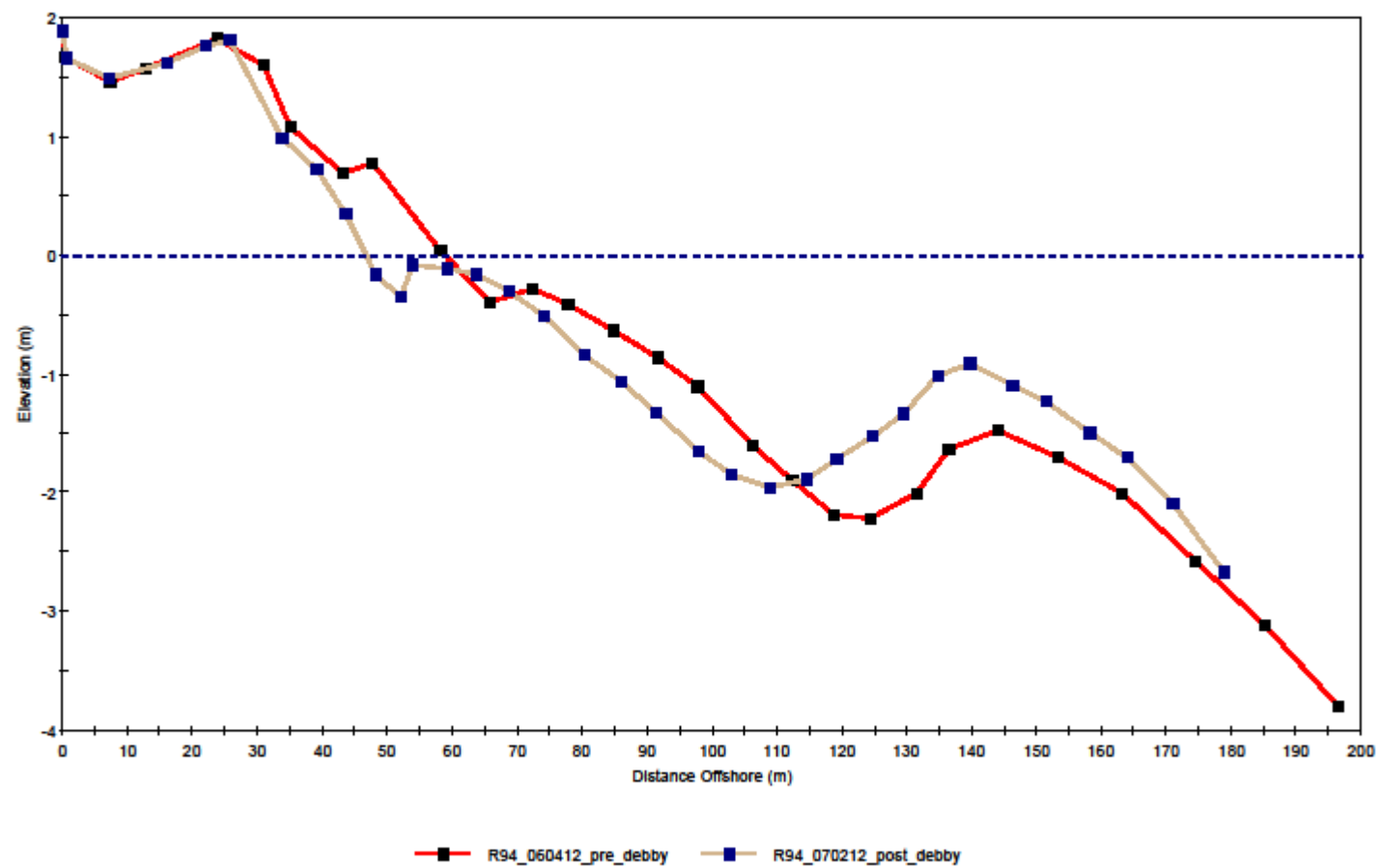
R92



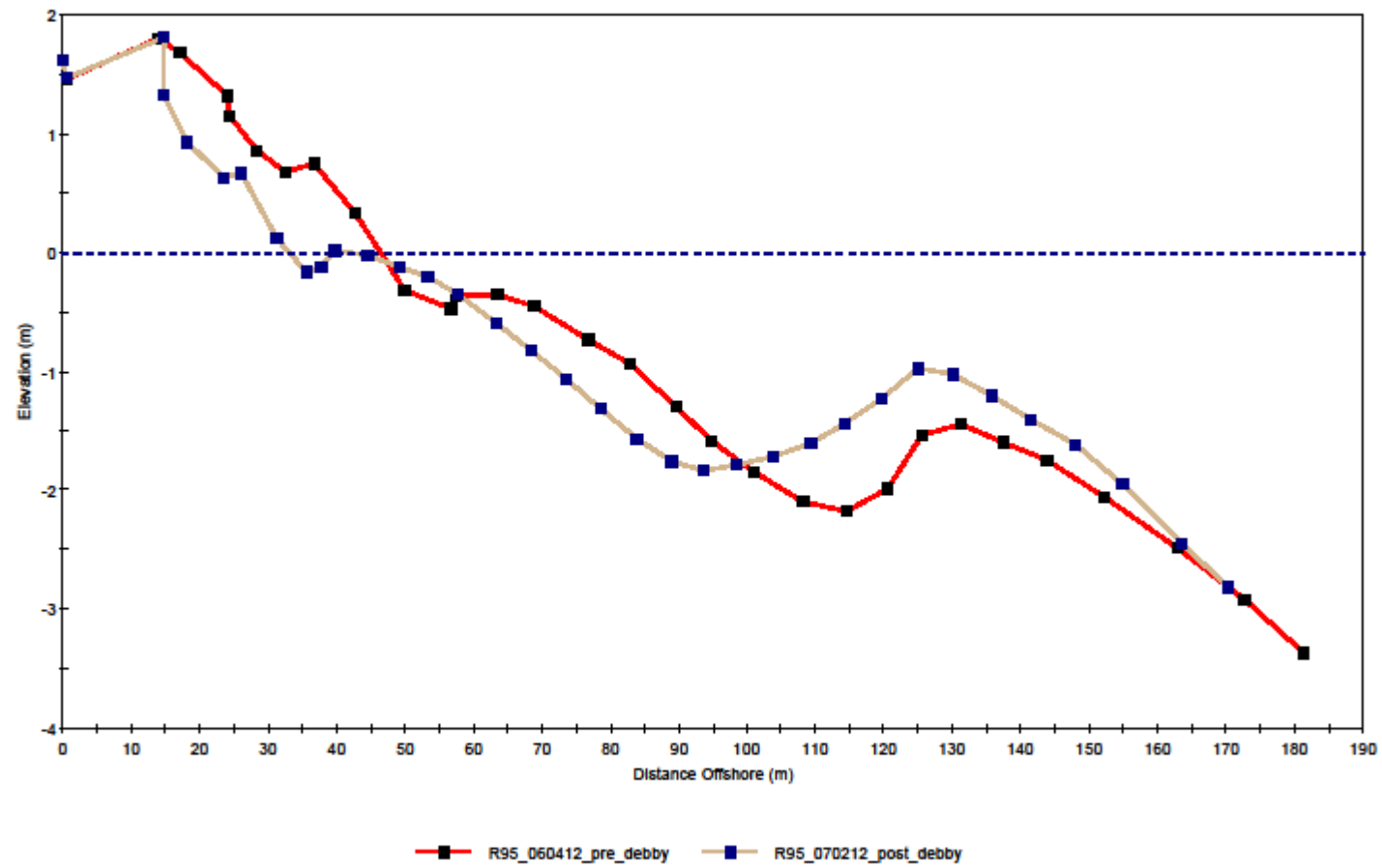
R93



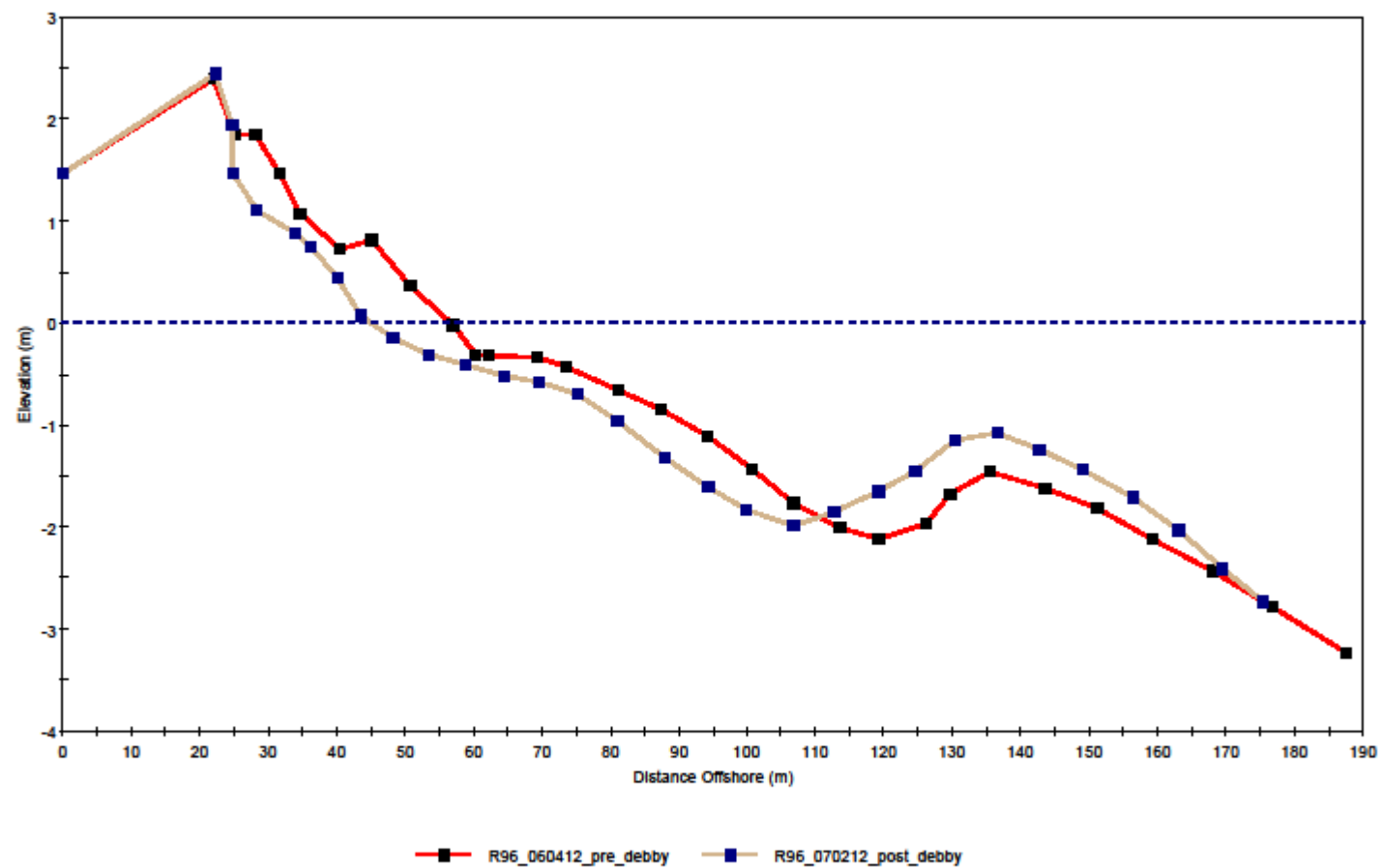
R94



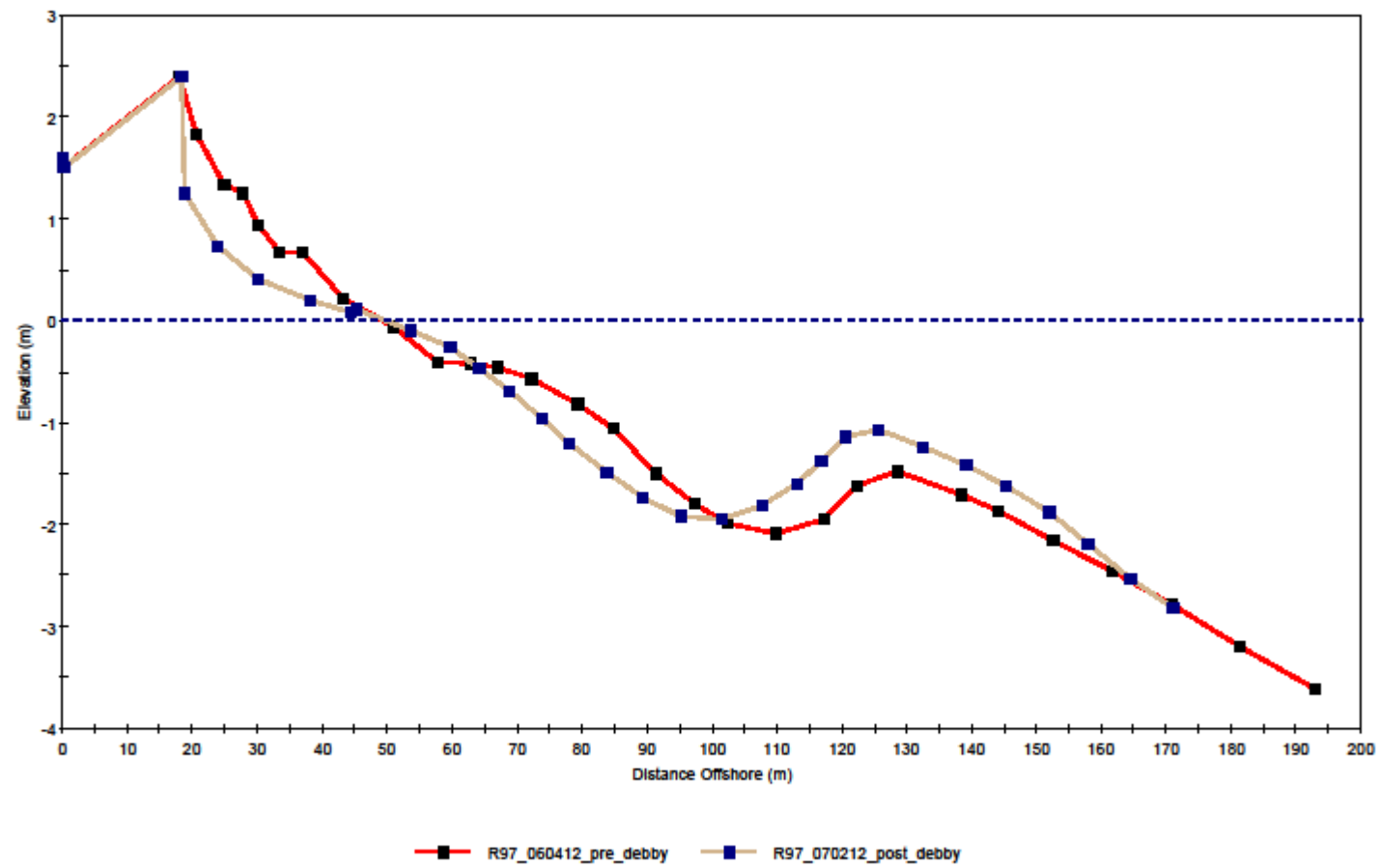
R95



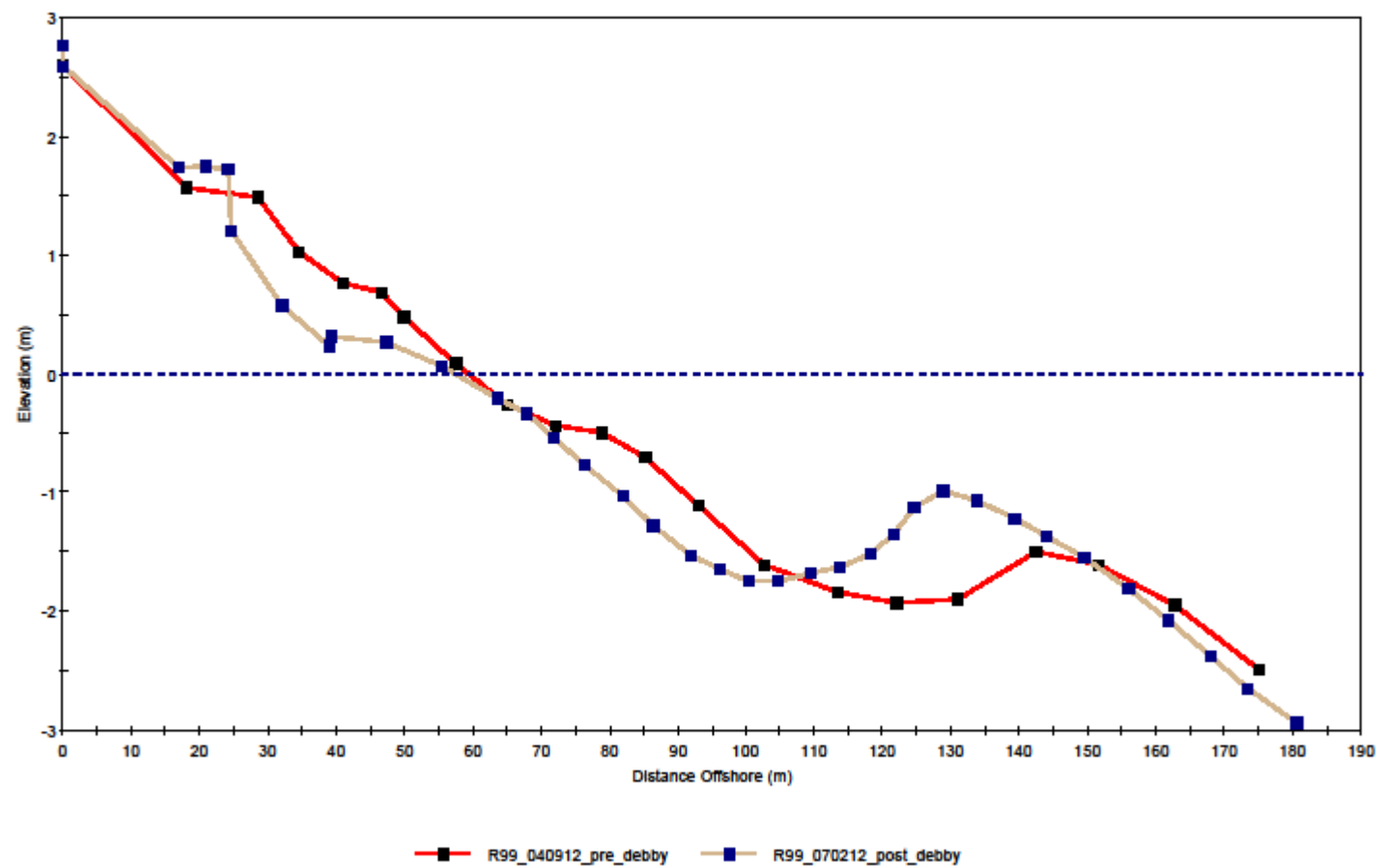
R96



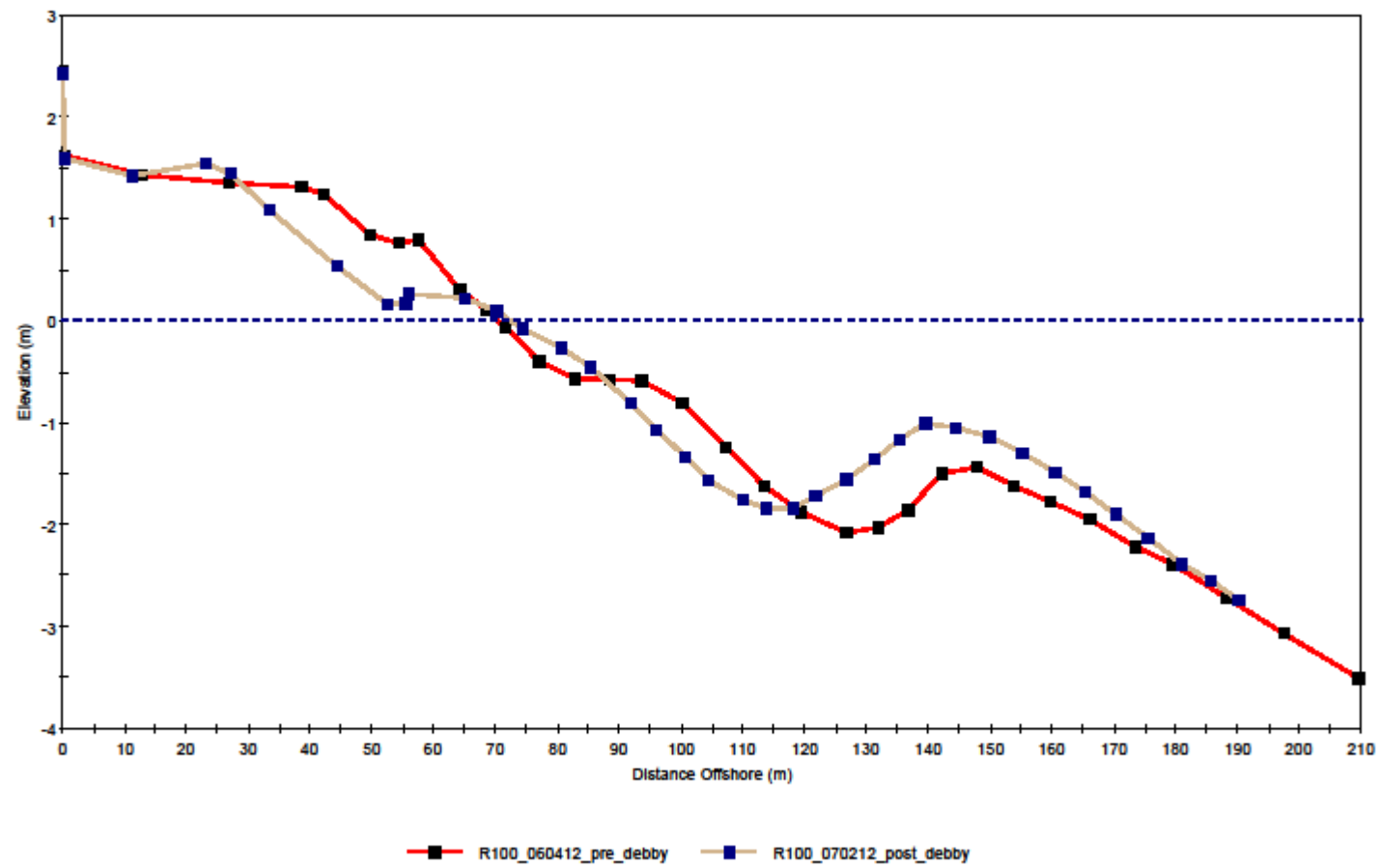
R97



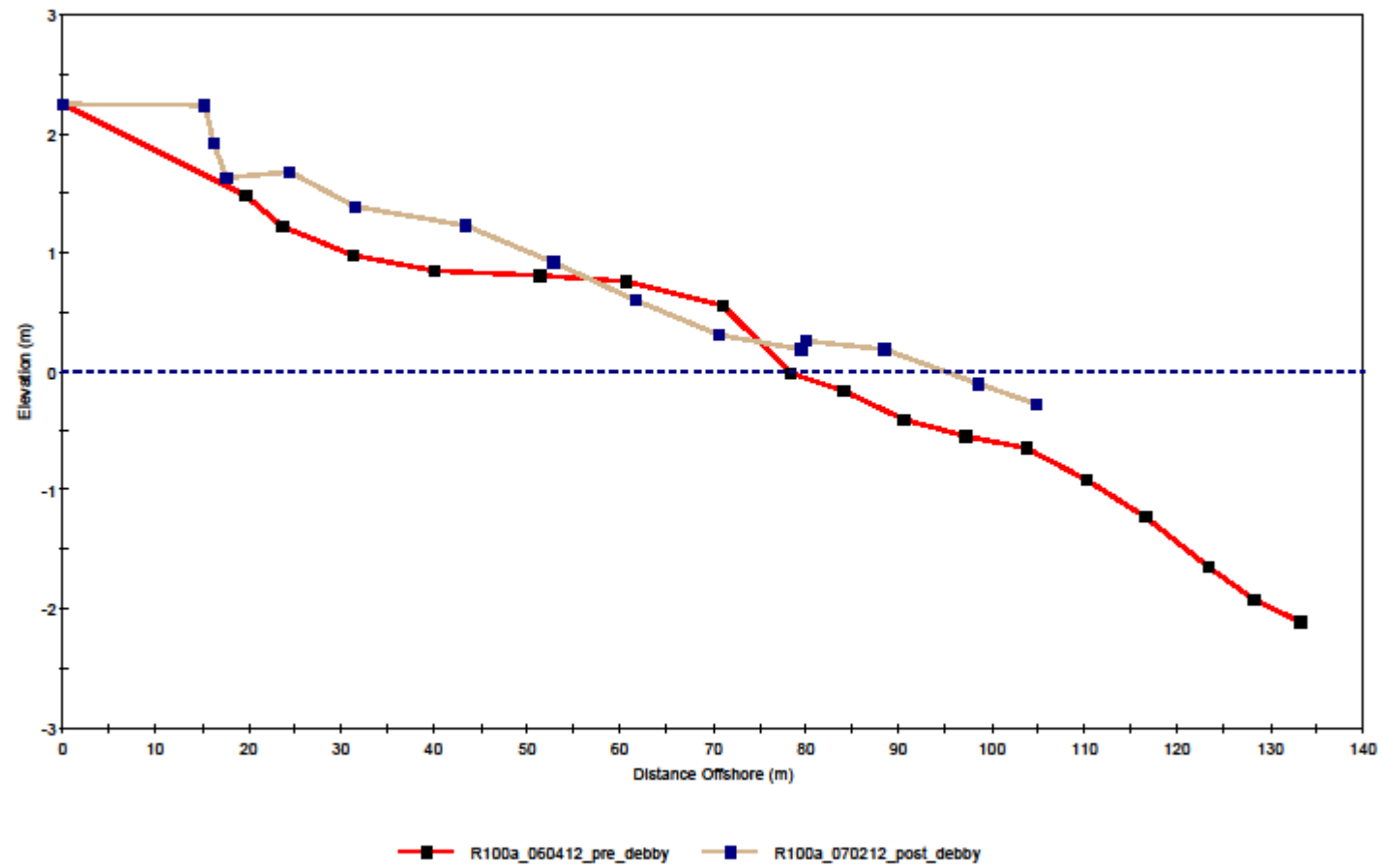
R99



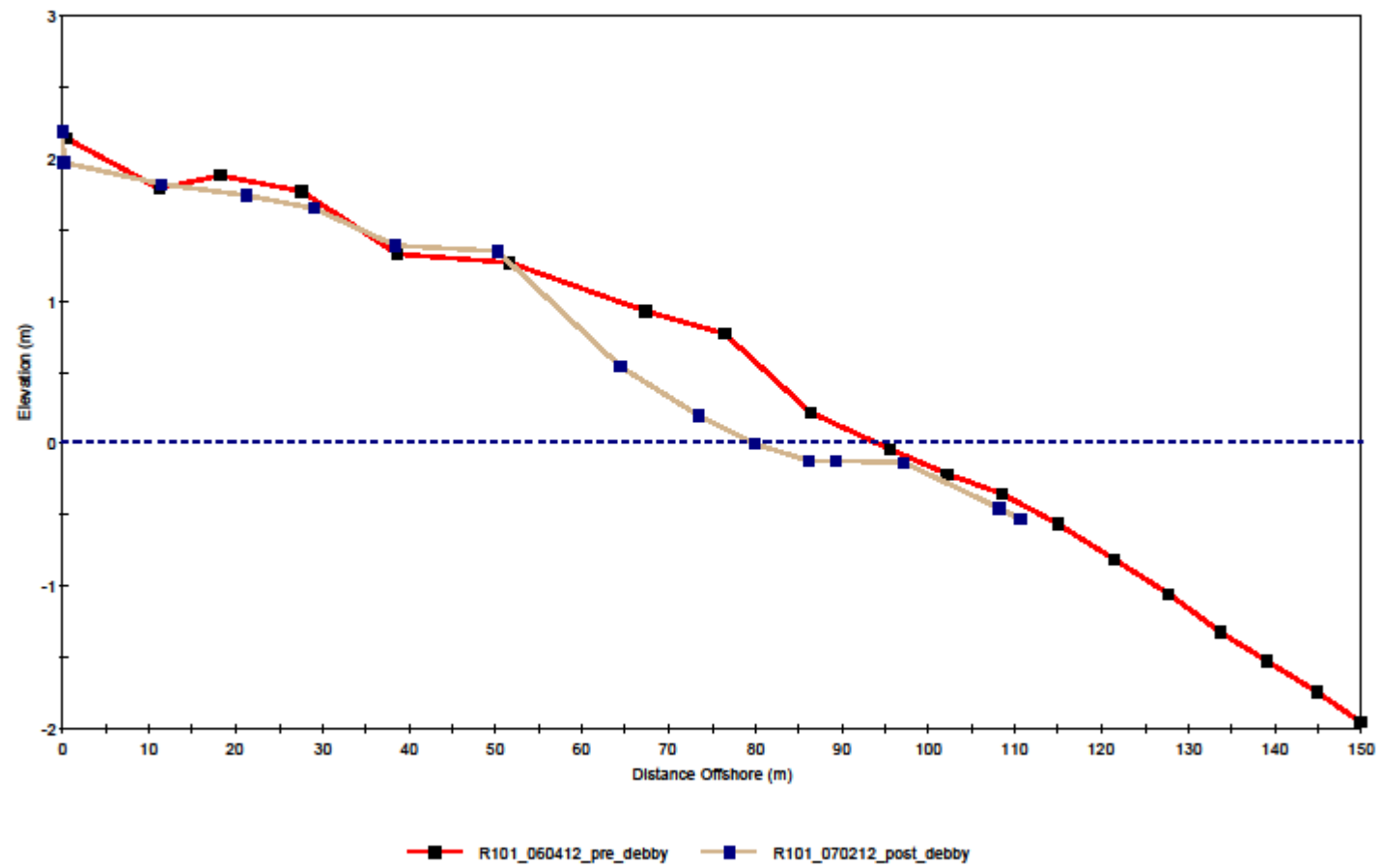
R100



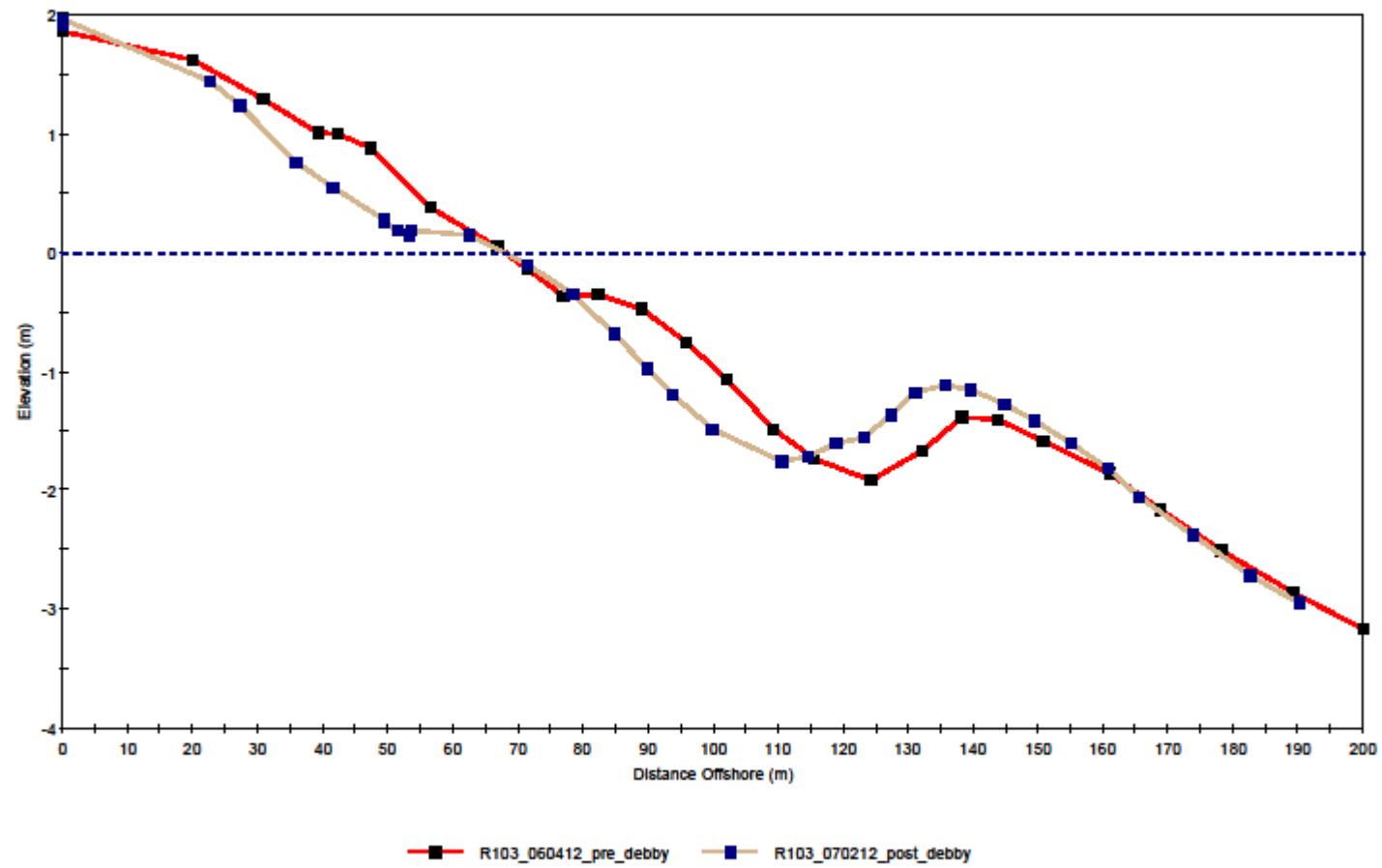
R100a



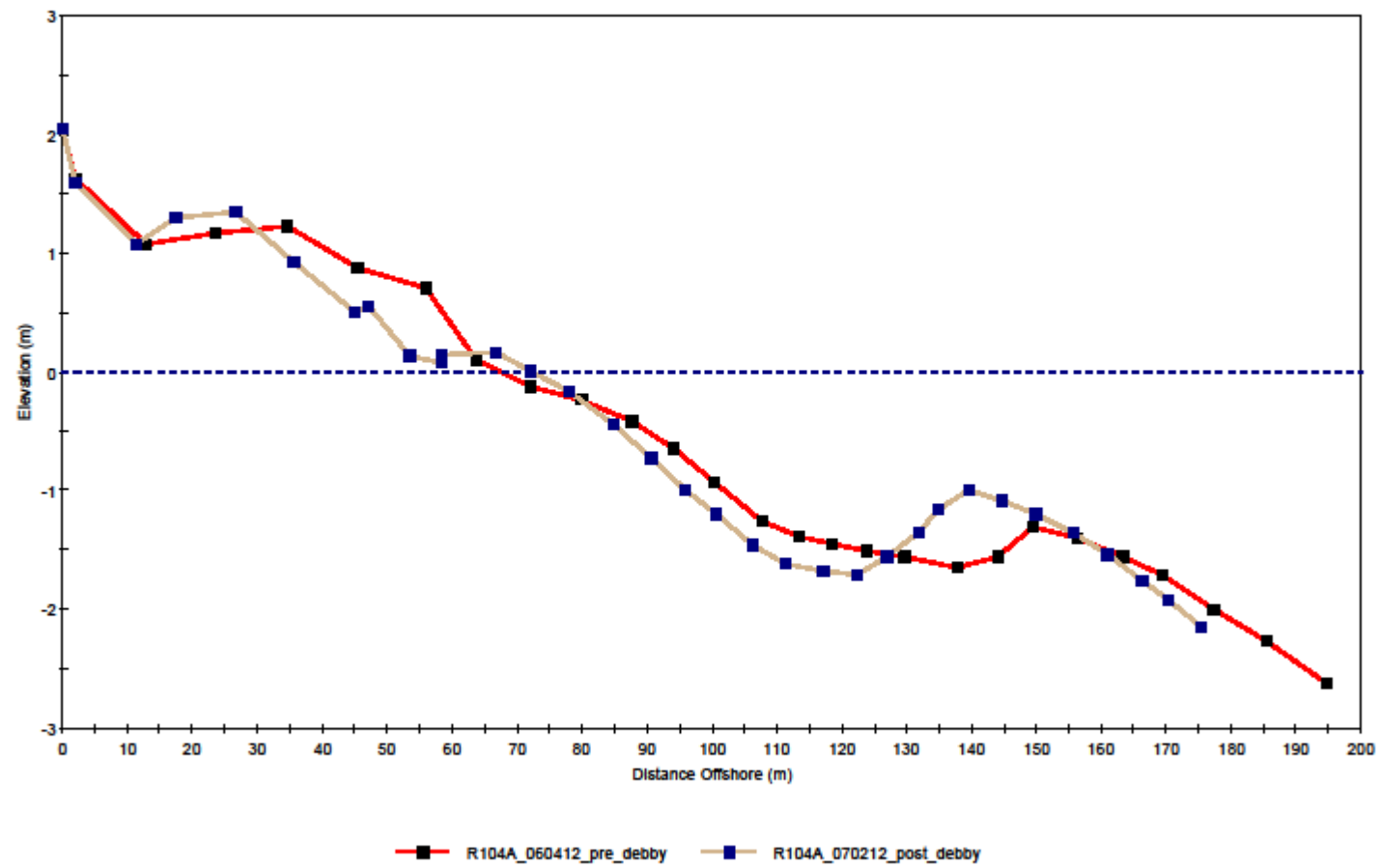
R101



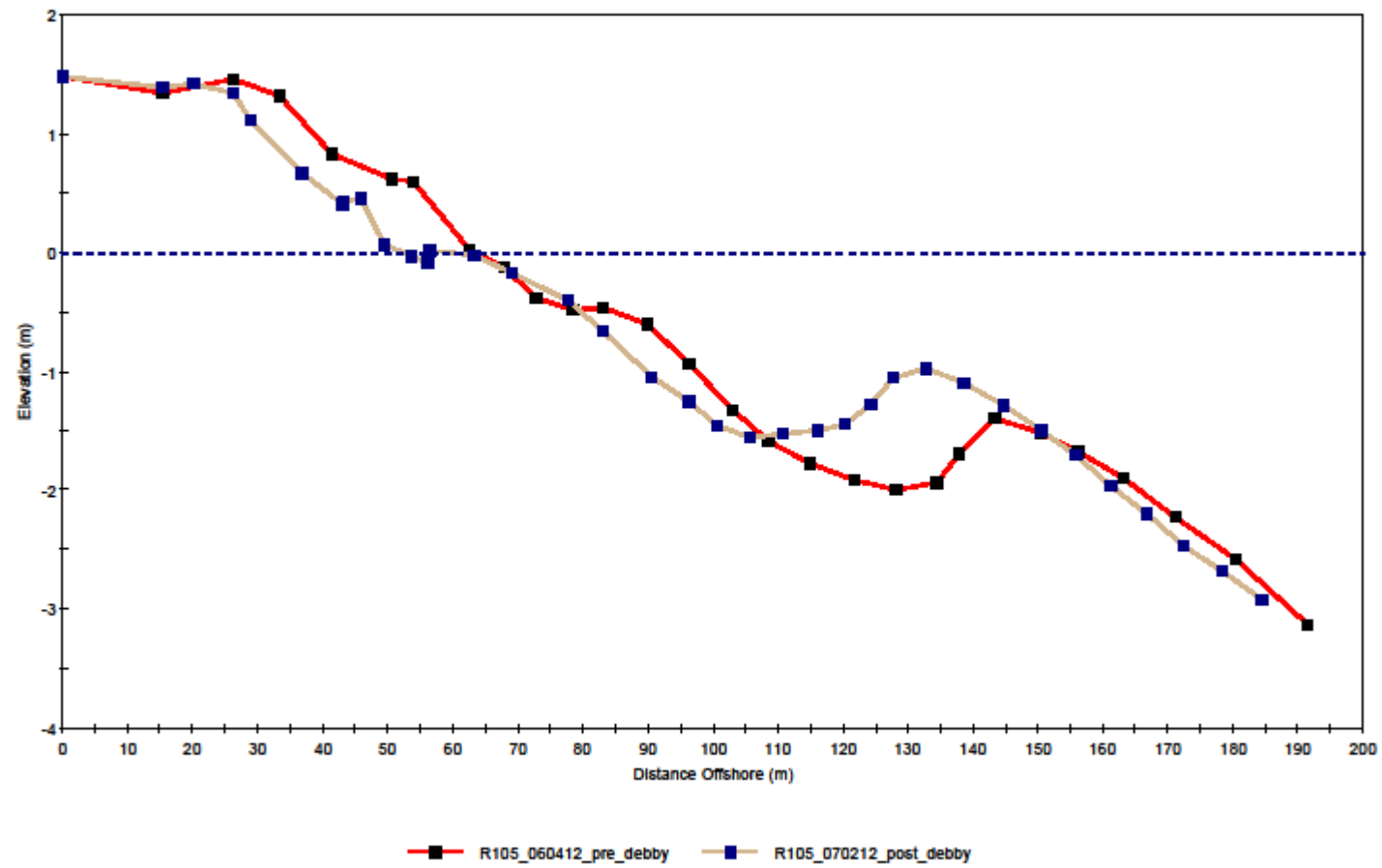
R103



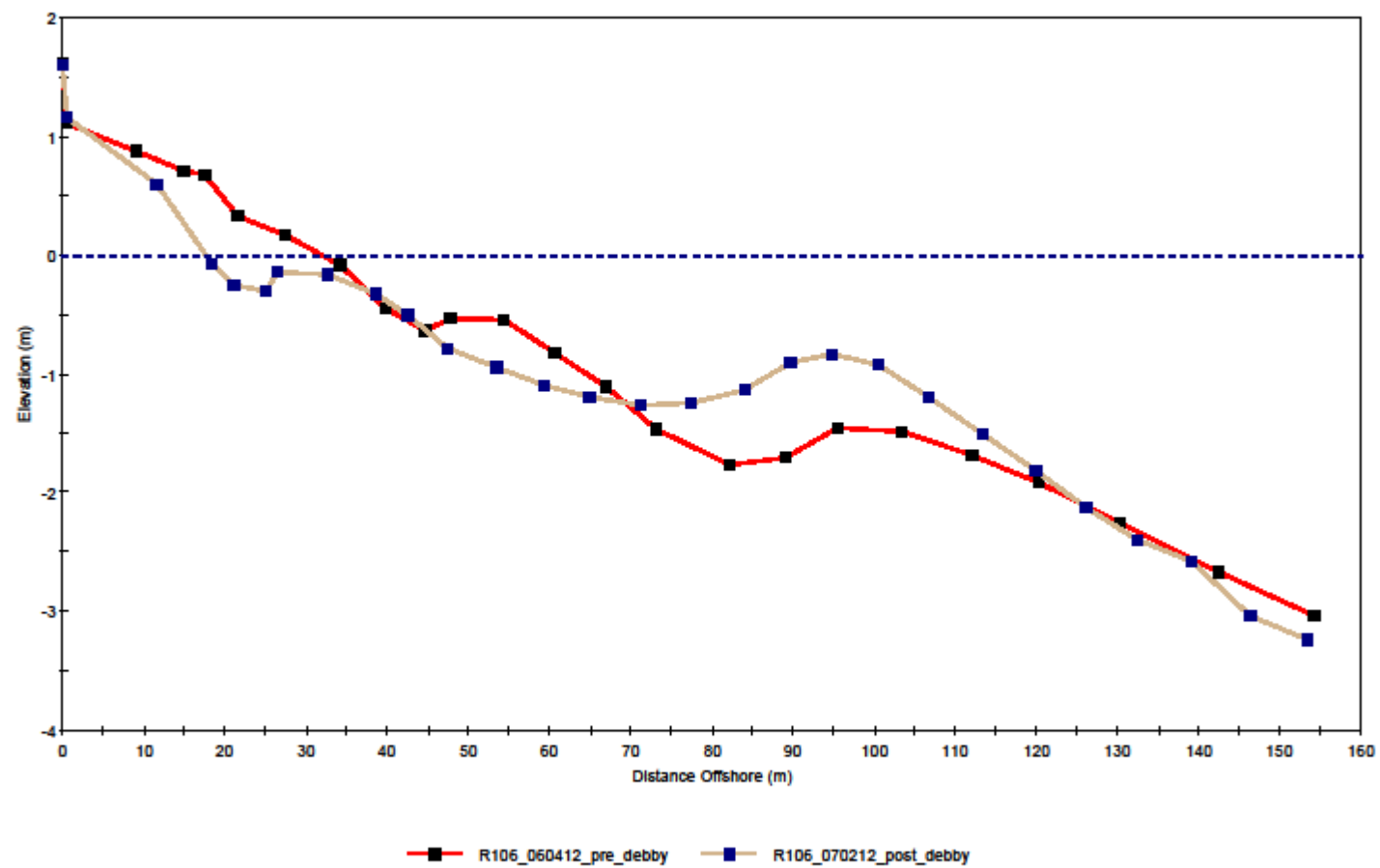
R104A



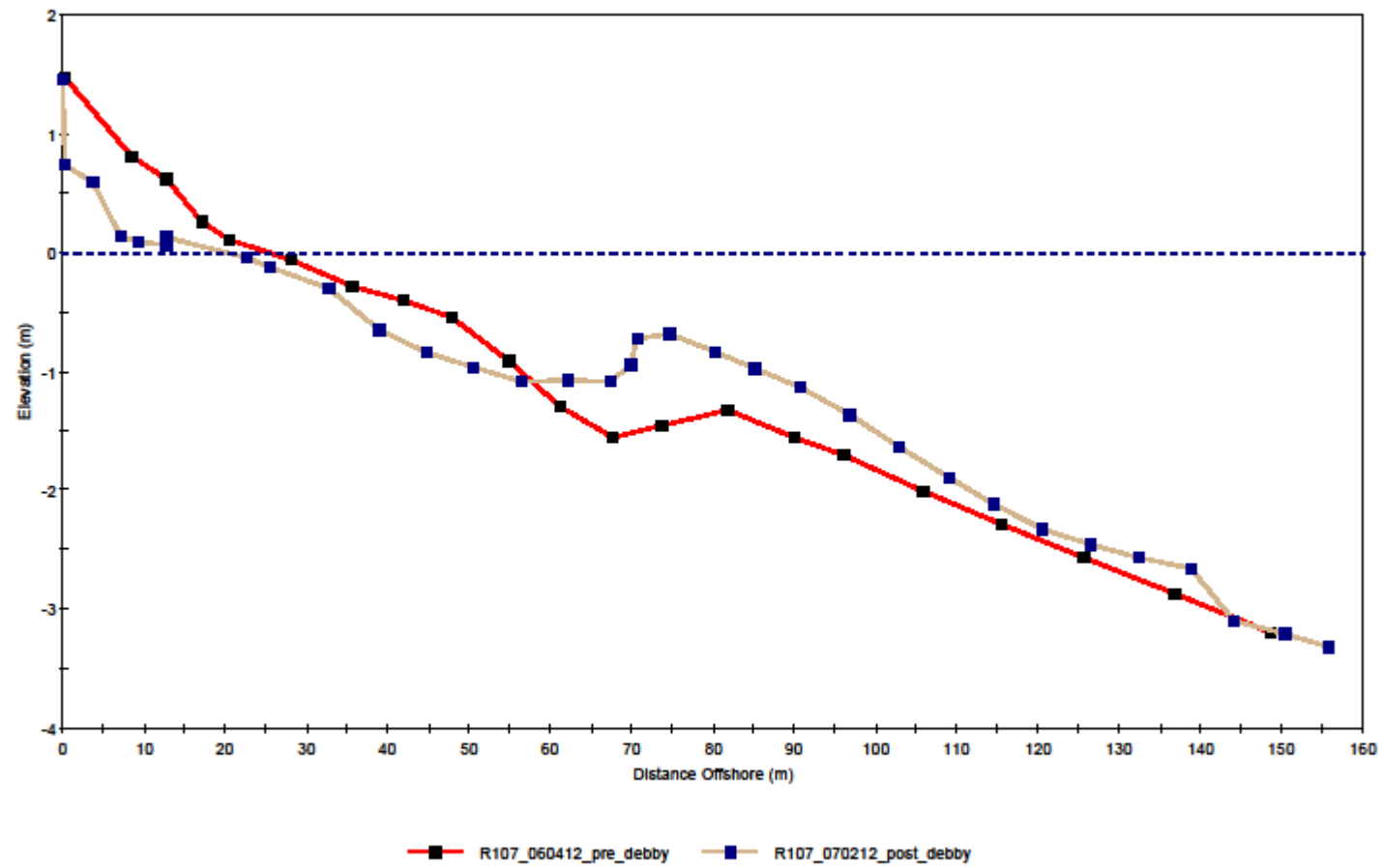
R105



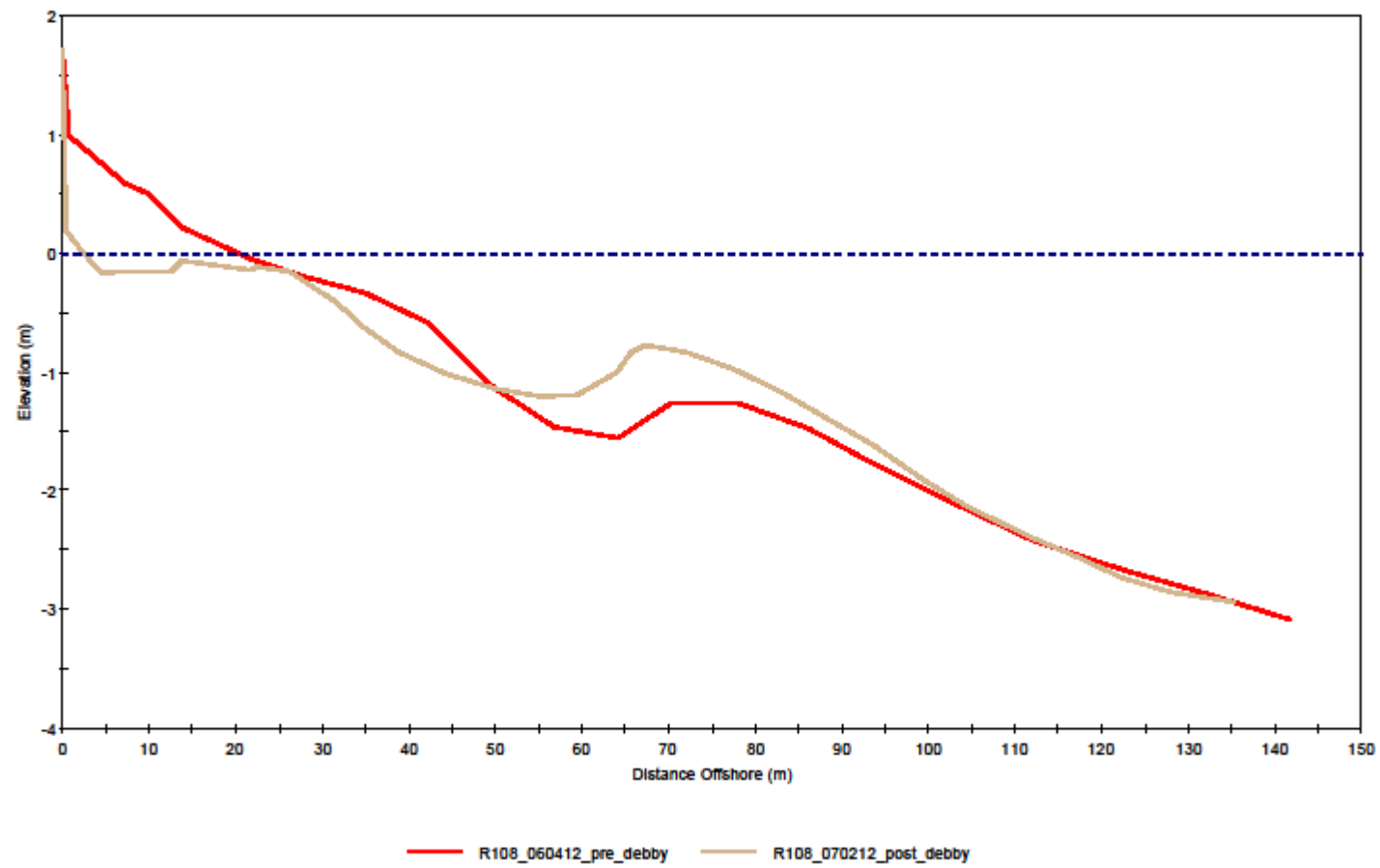
R106



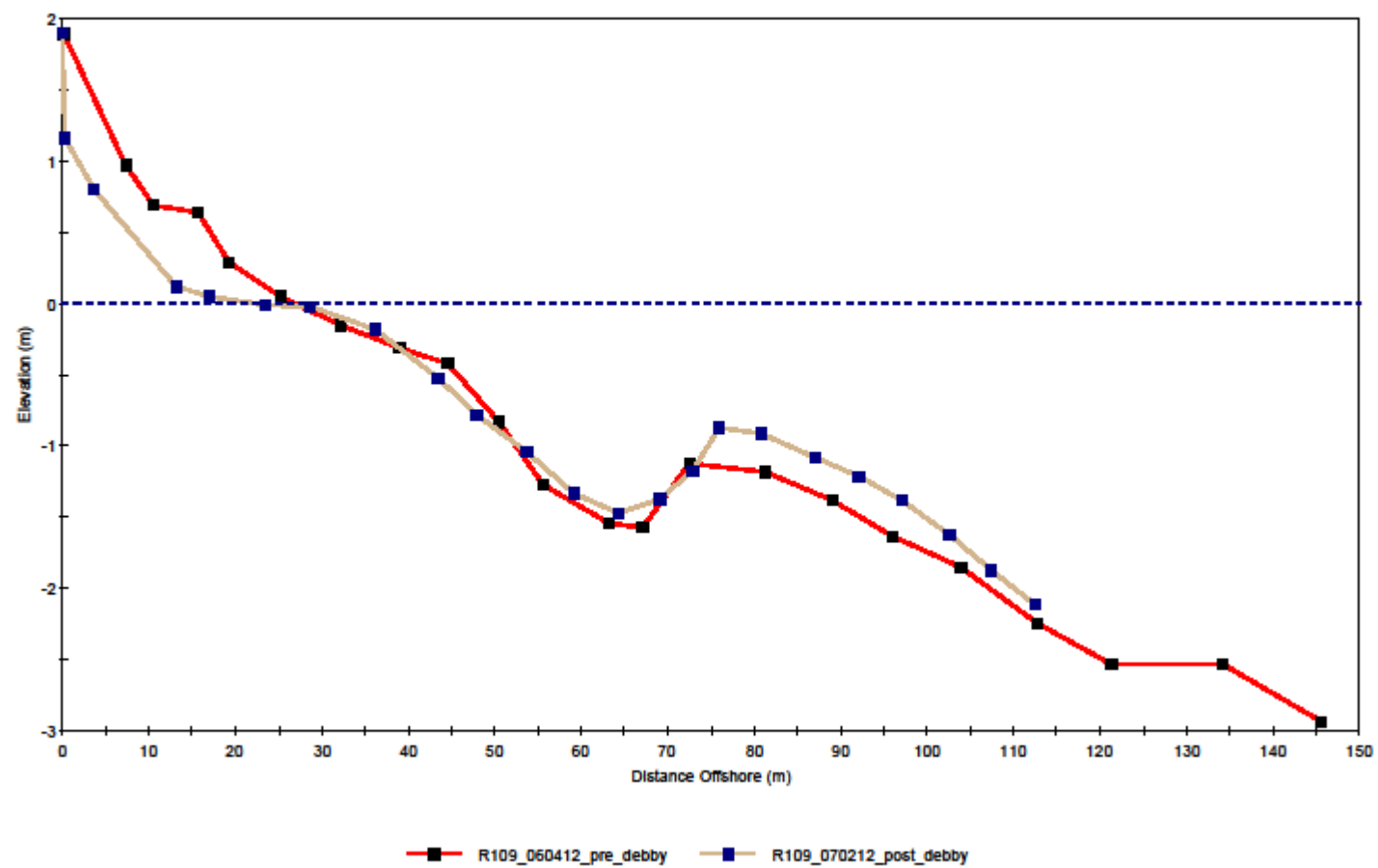
R107



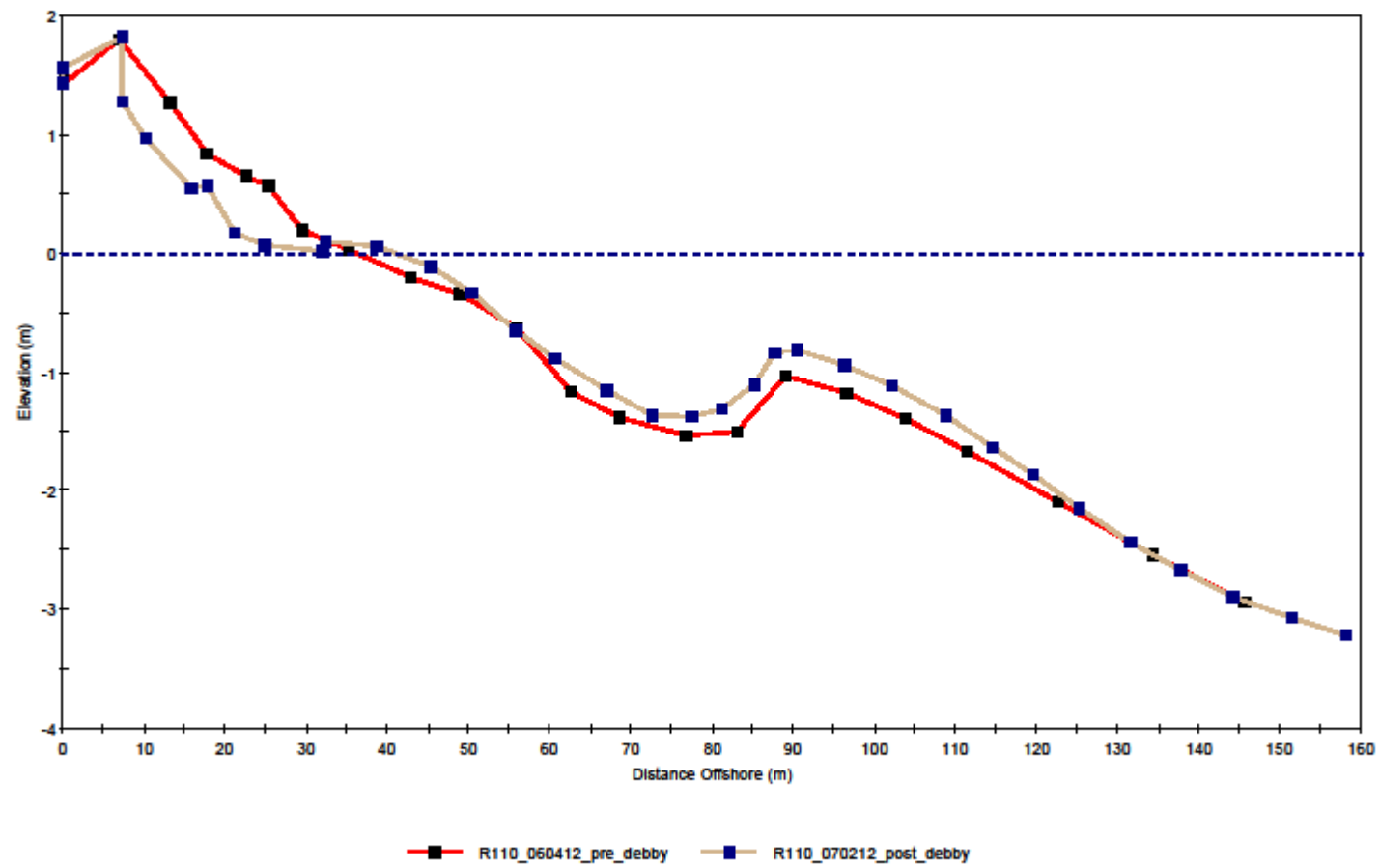
R108



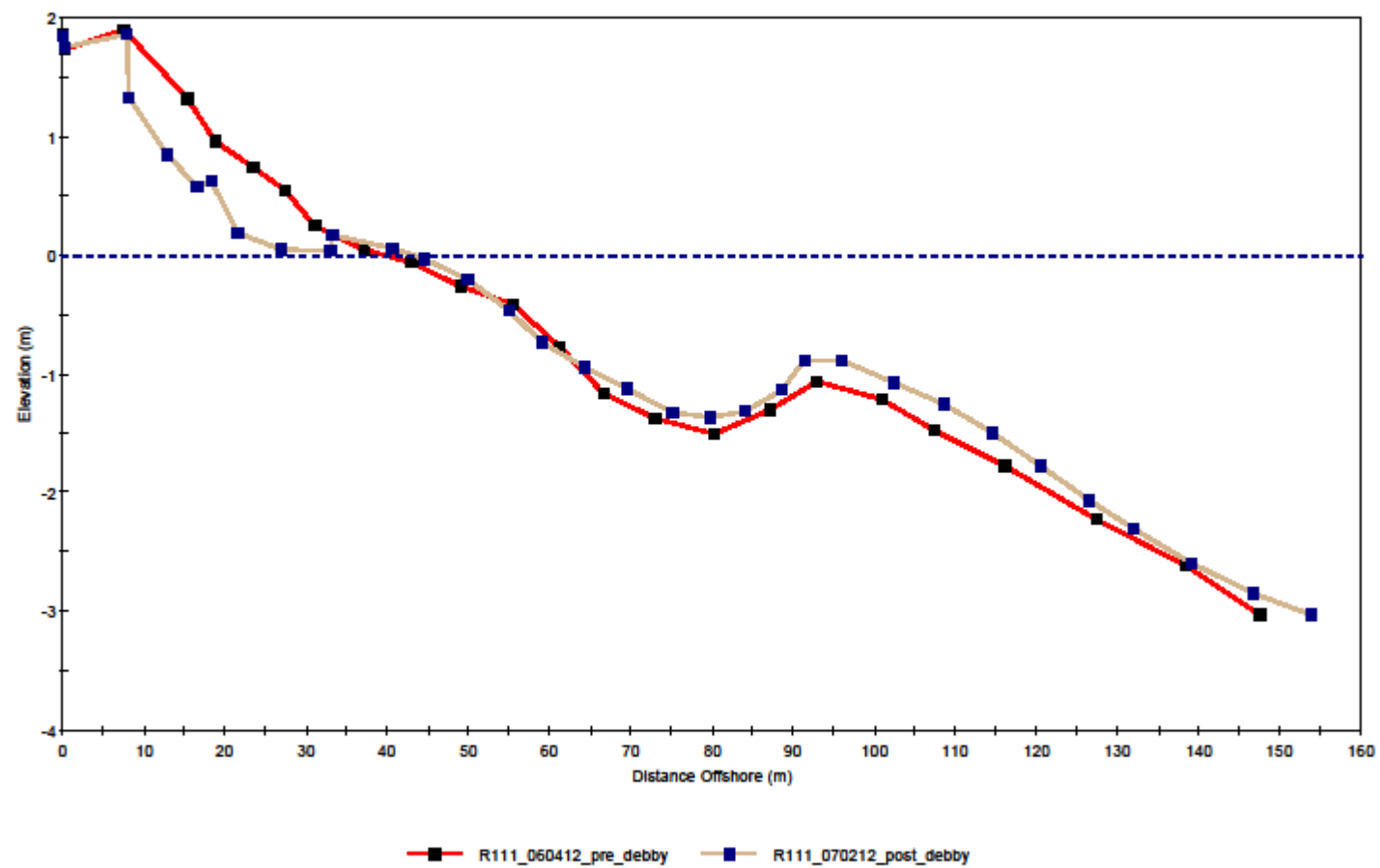
R109



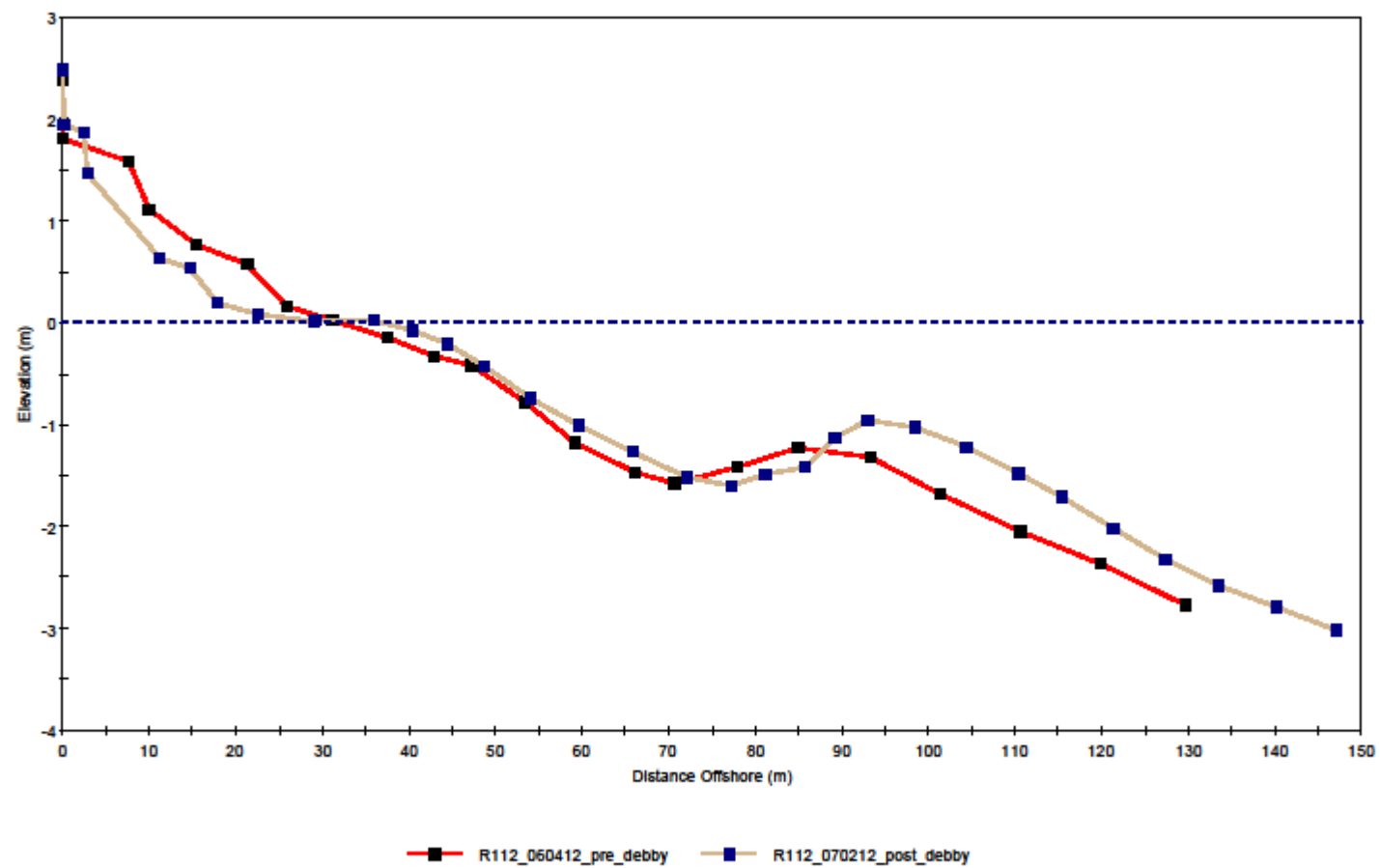
R110



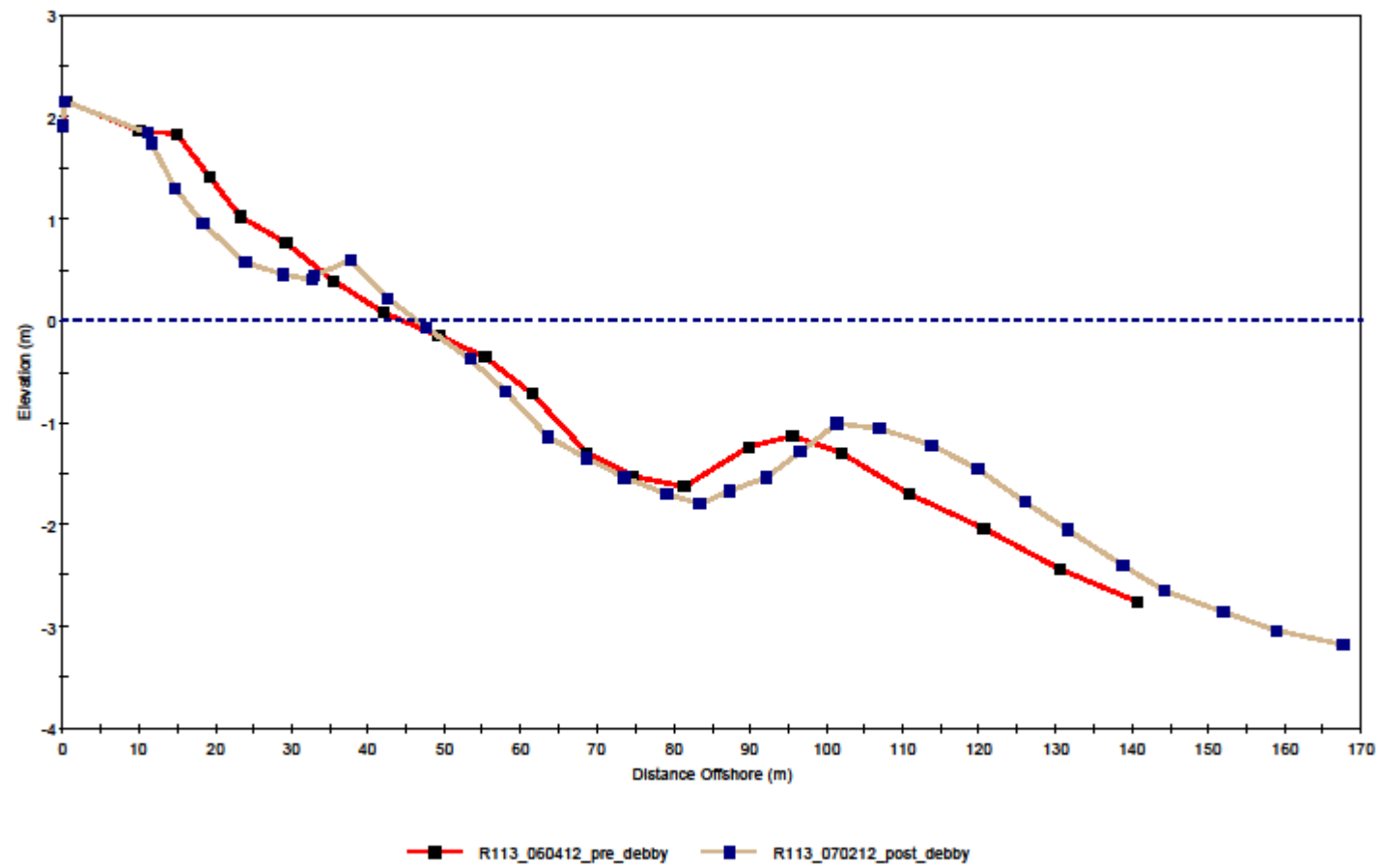
R111



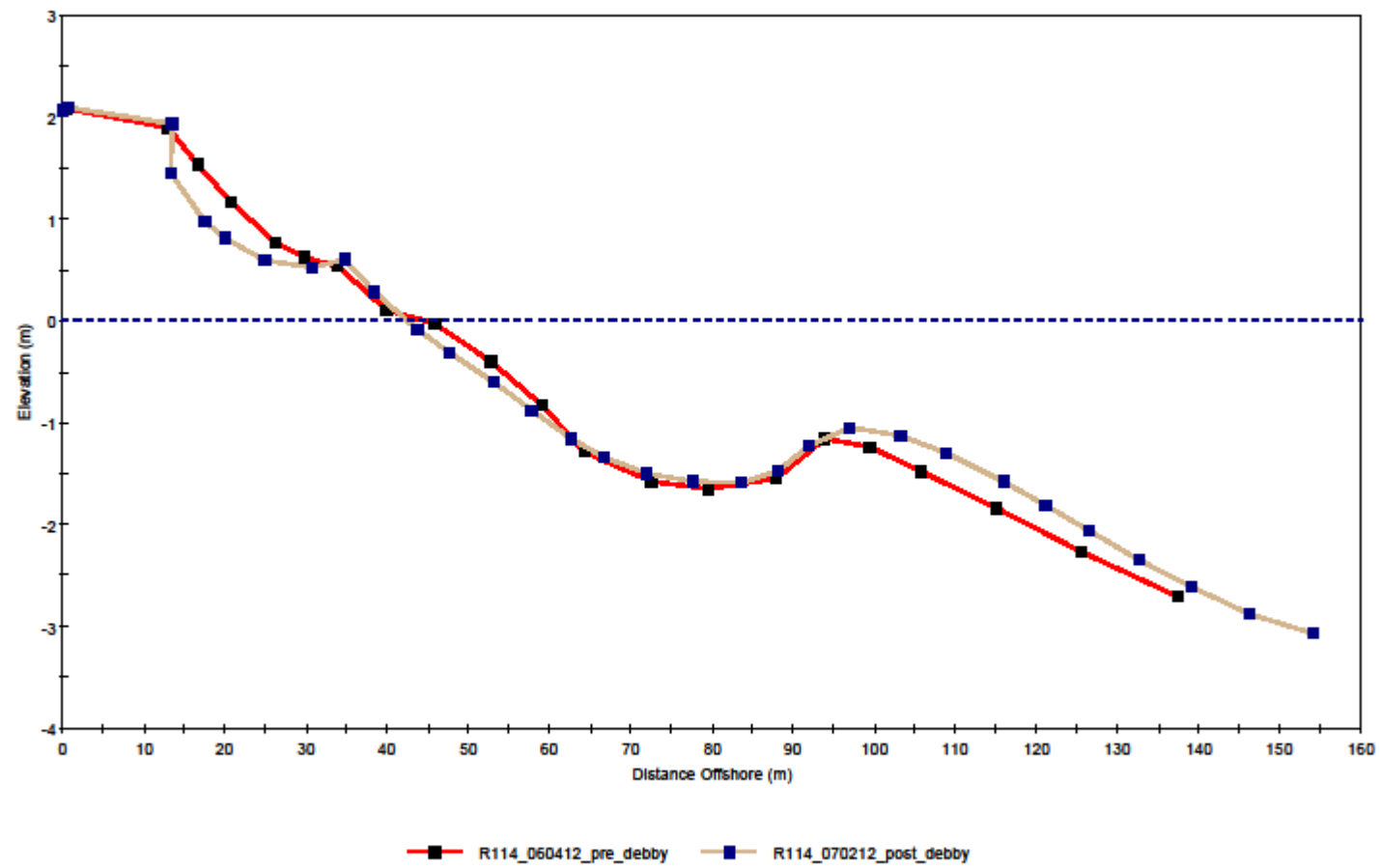
R112



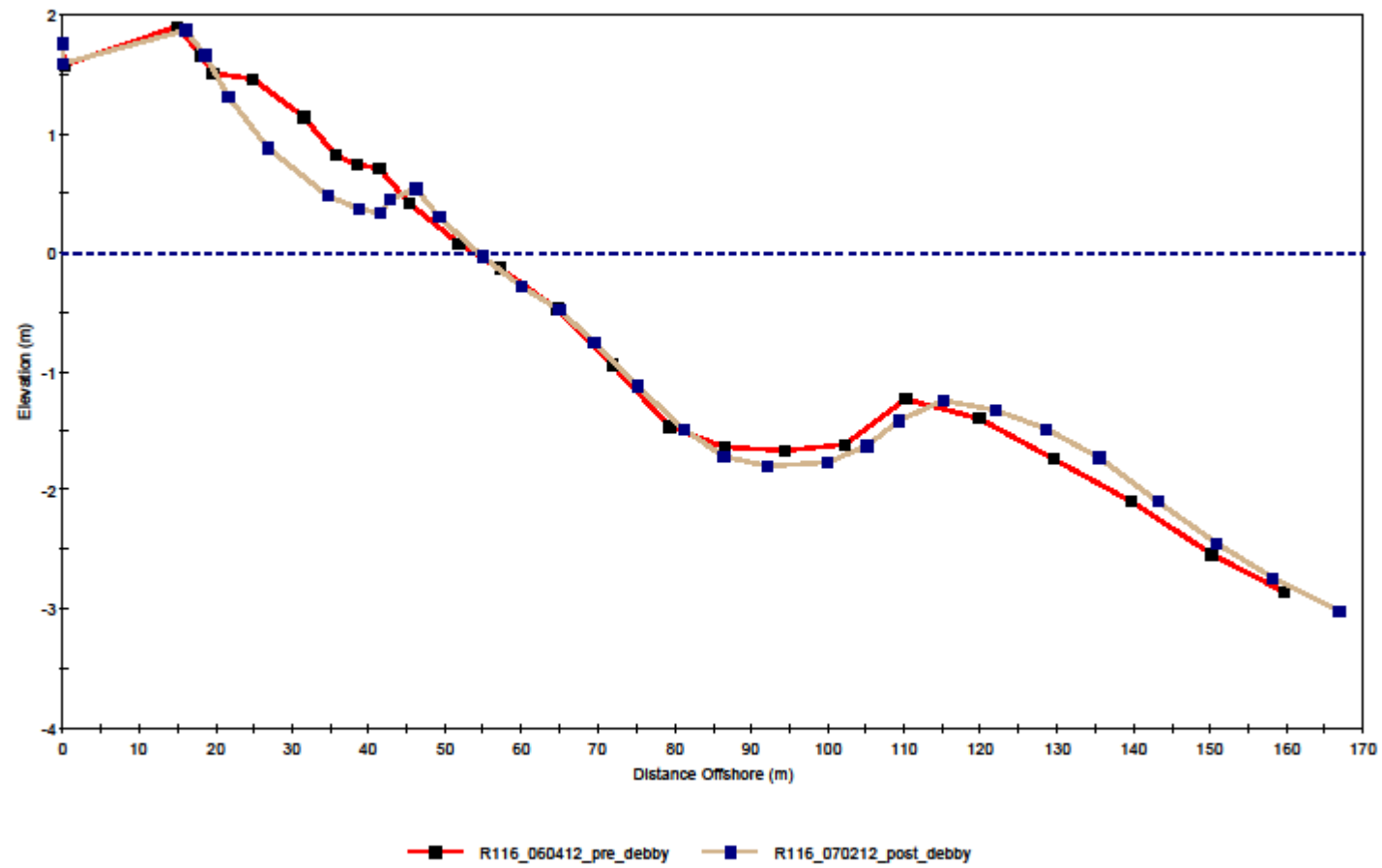
R113



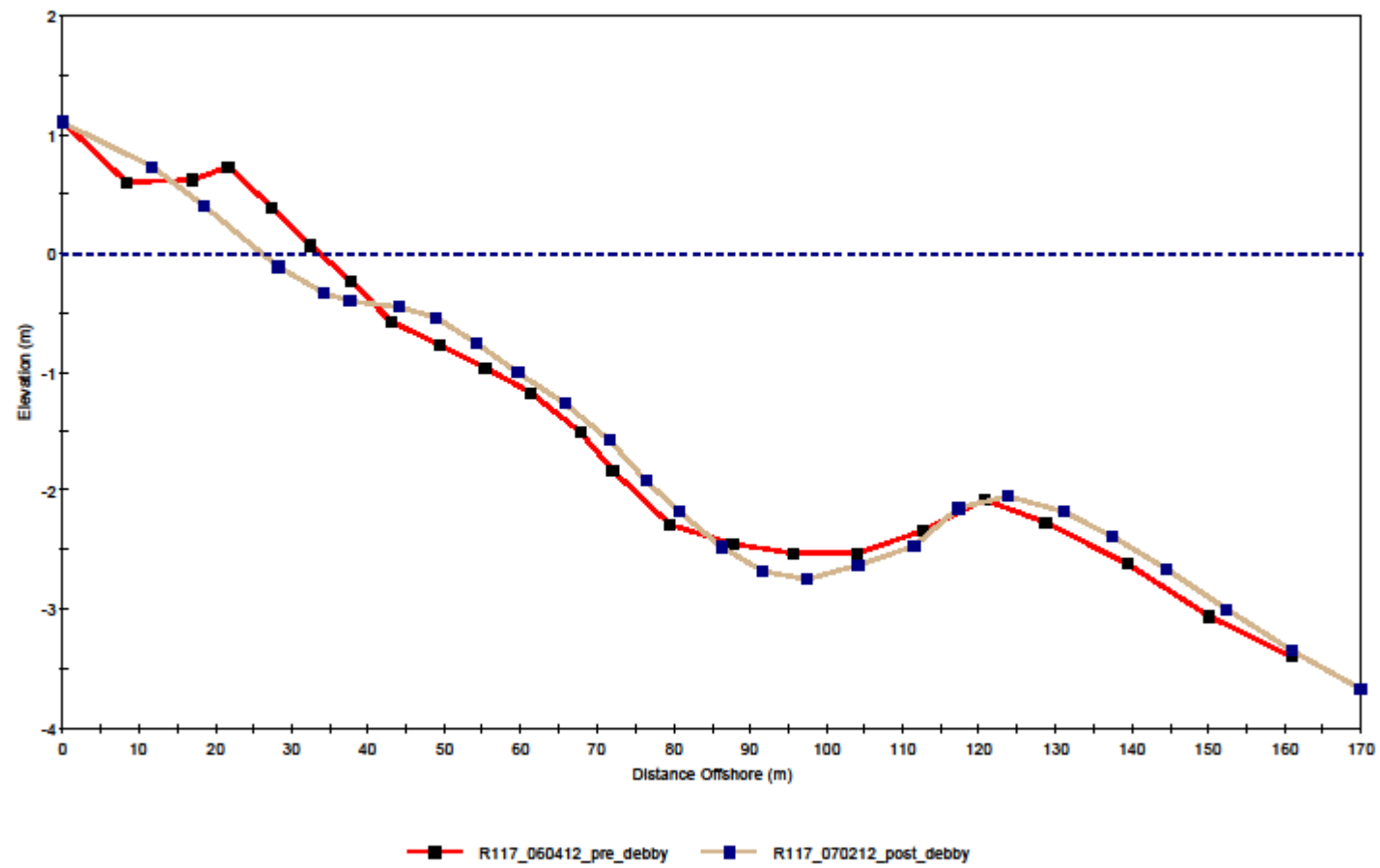
R114



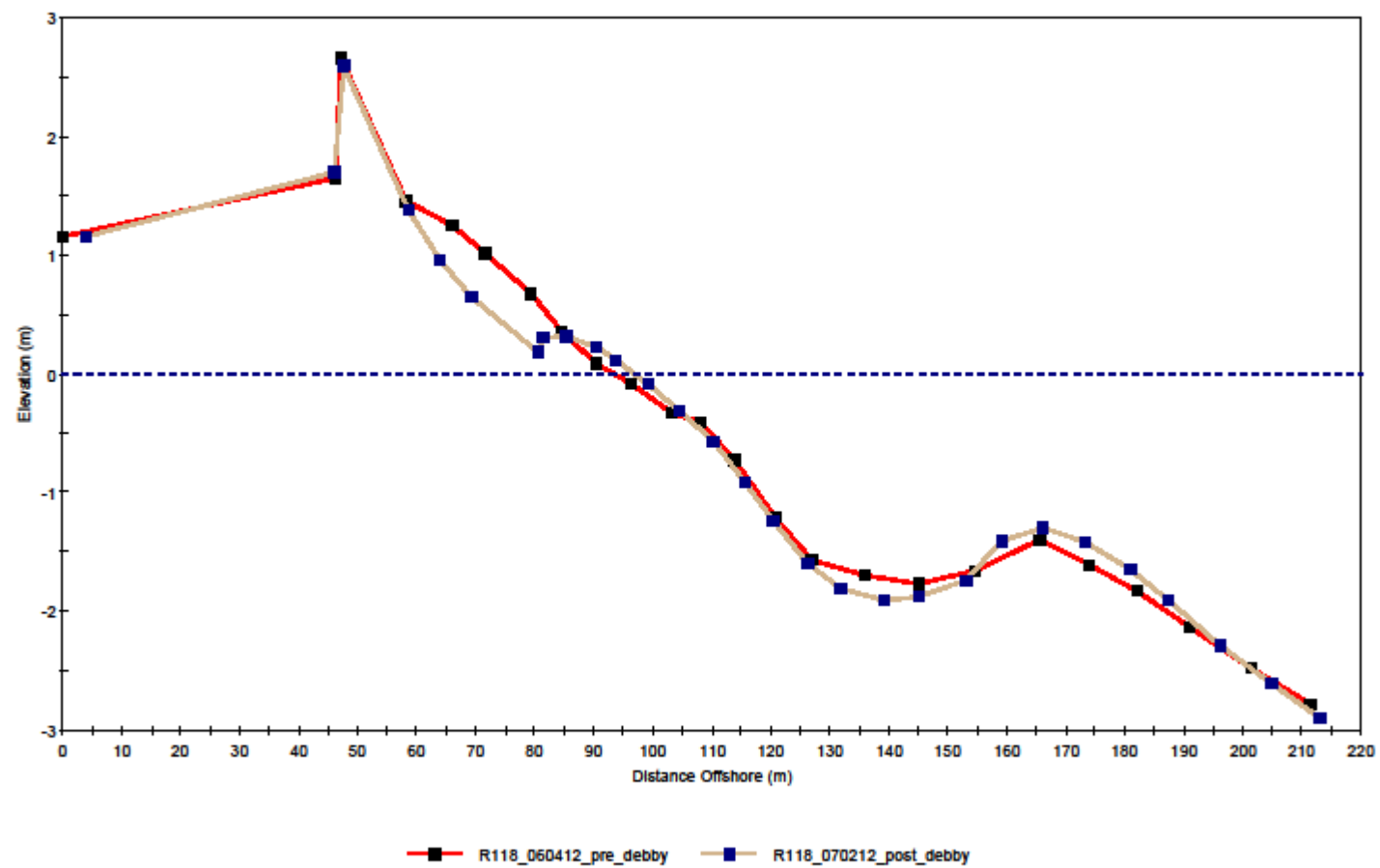
R116



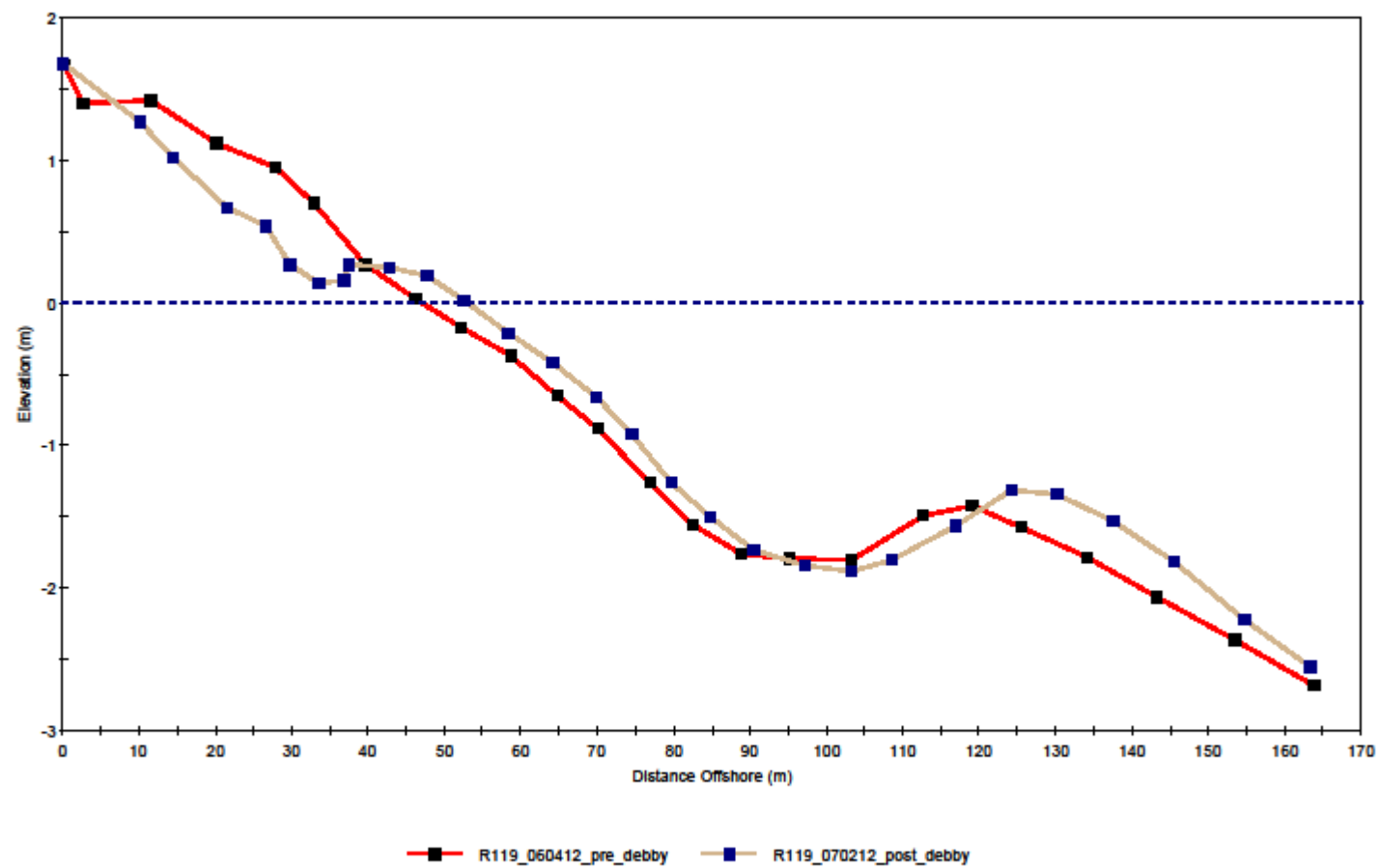
R117



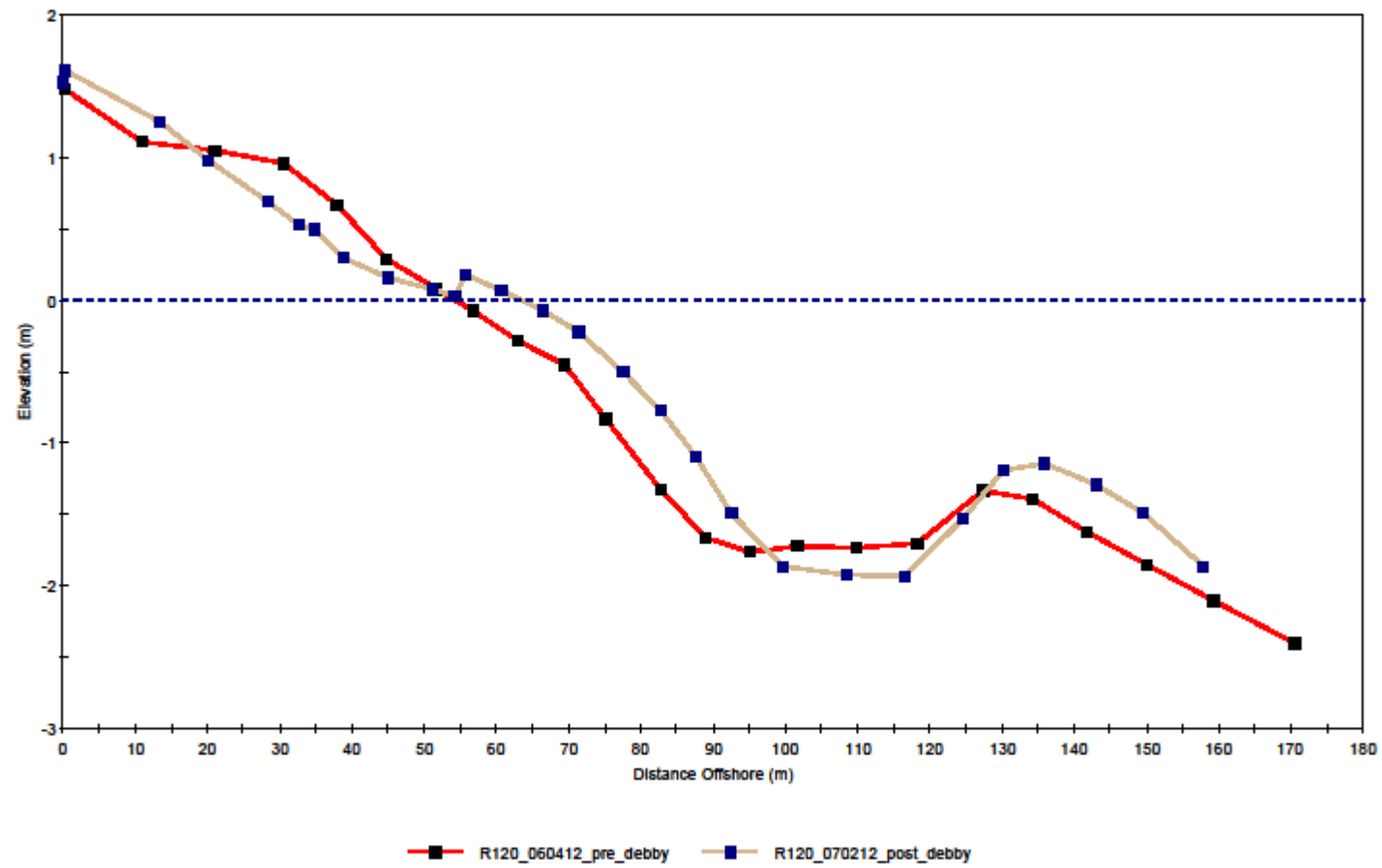
R118



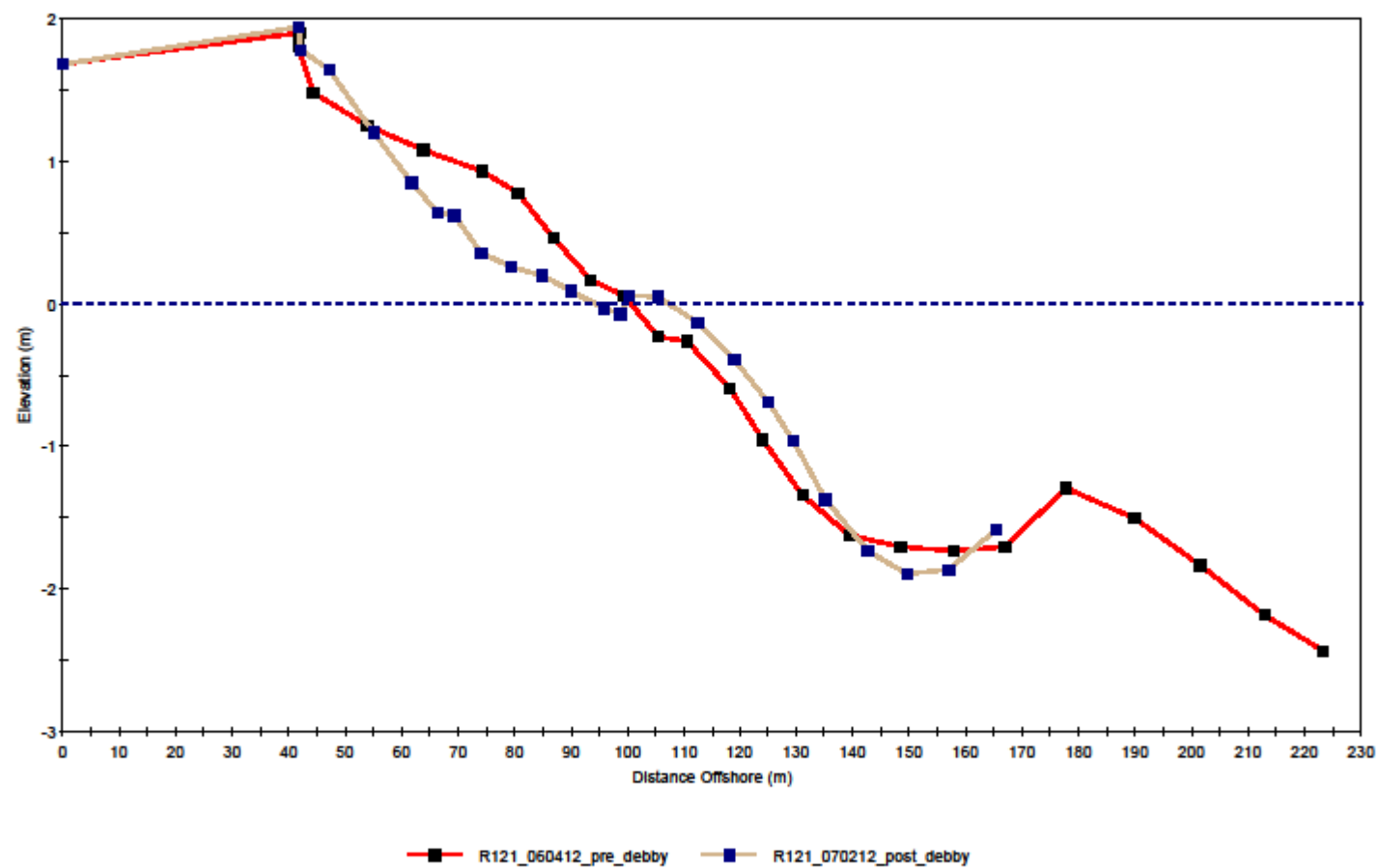
R119



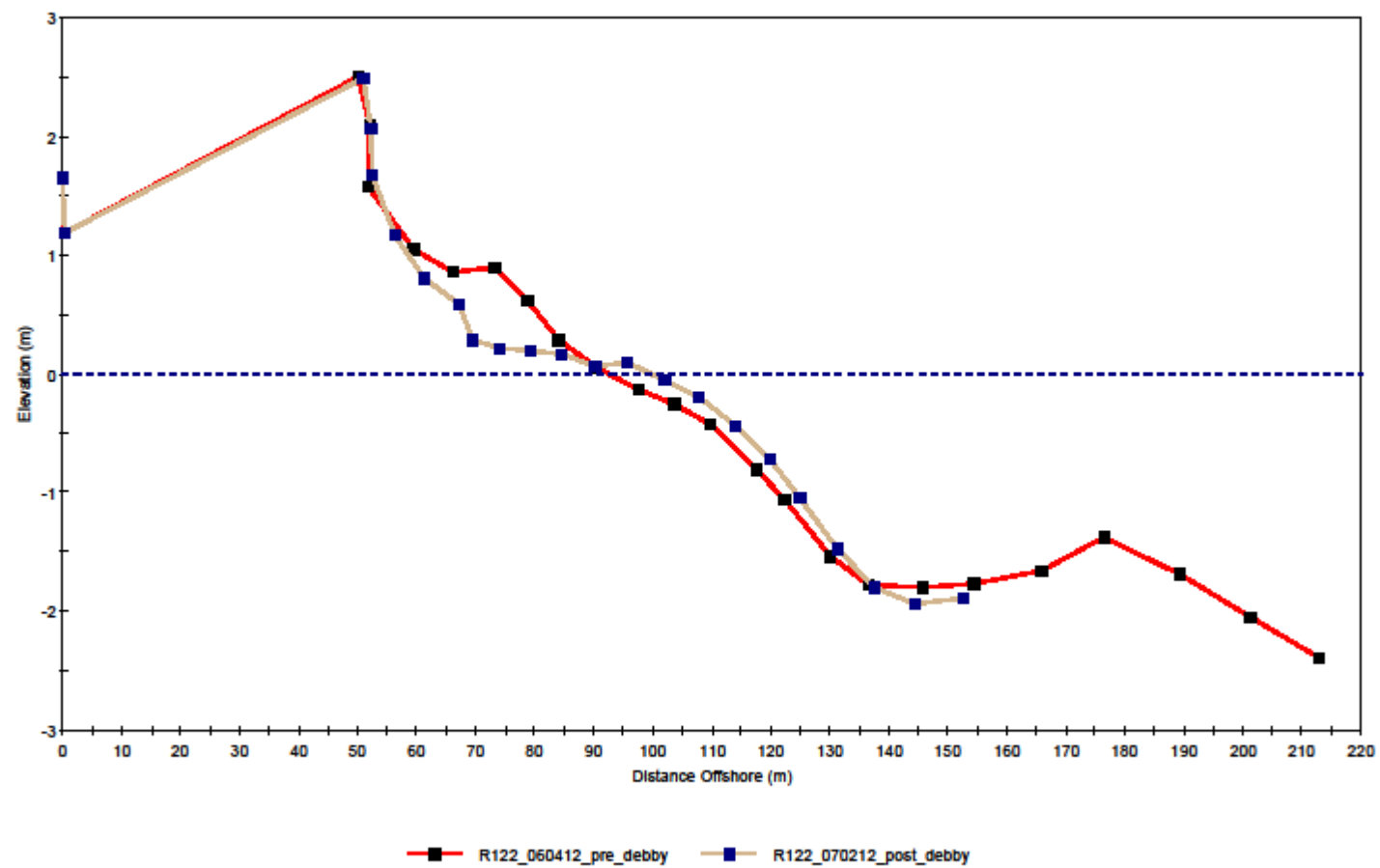
R120



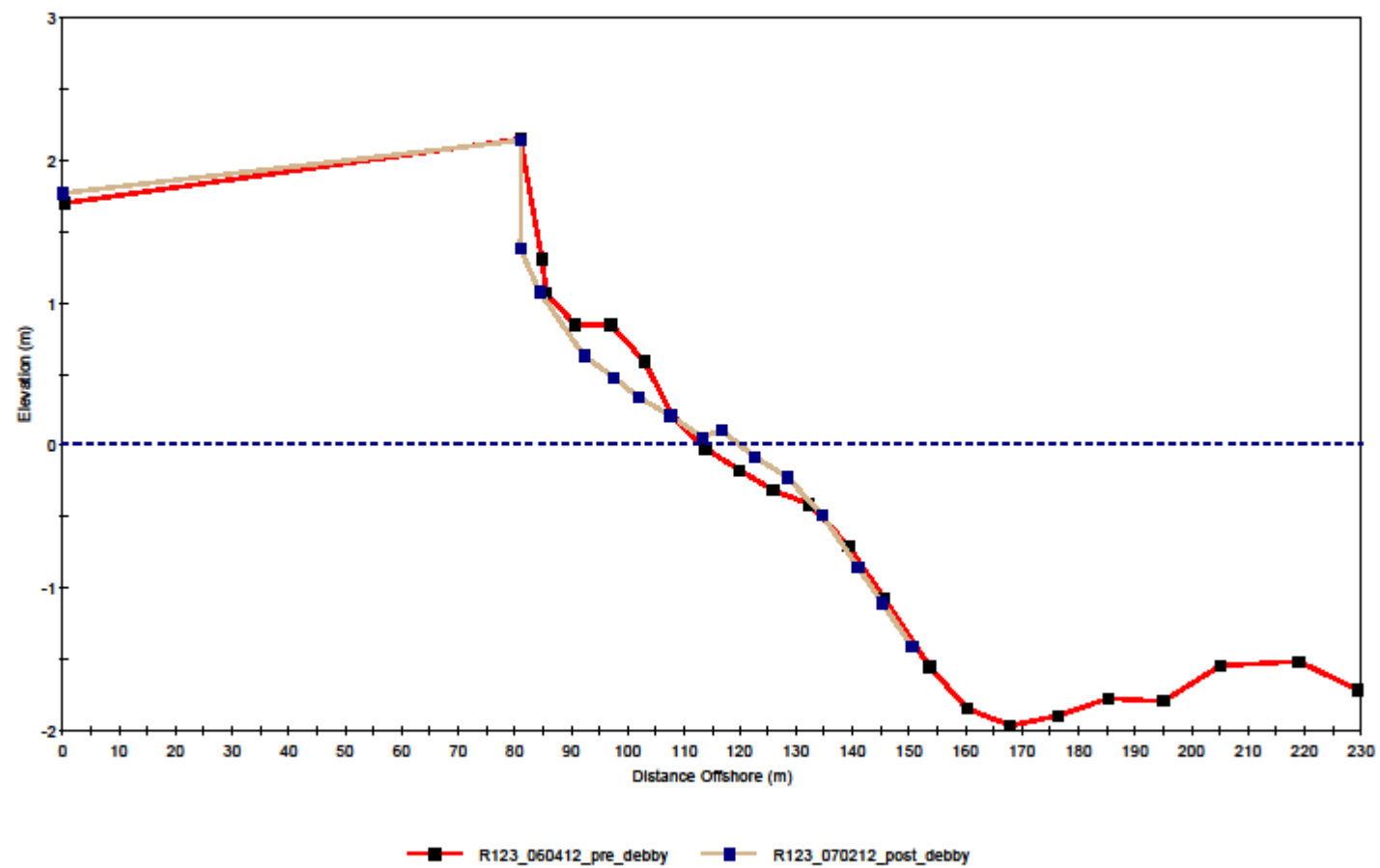
R121



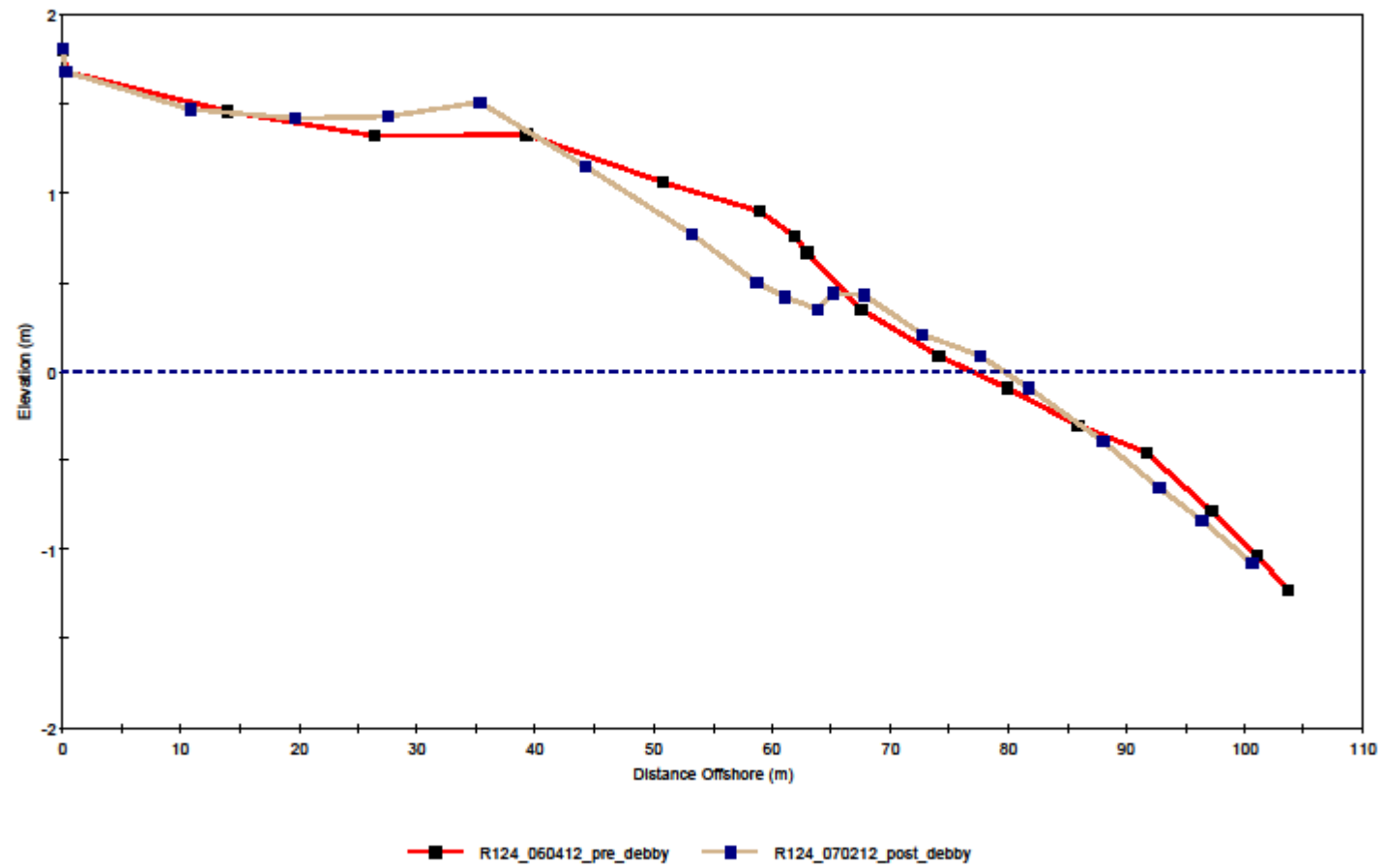
R122



R123

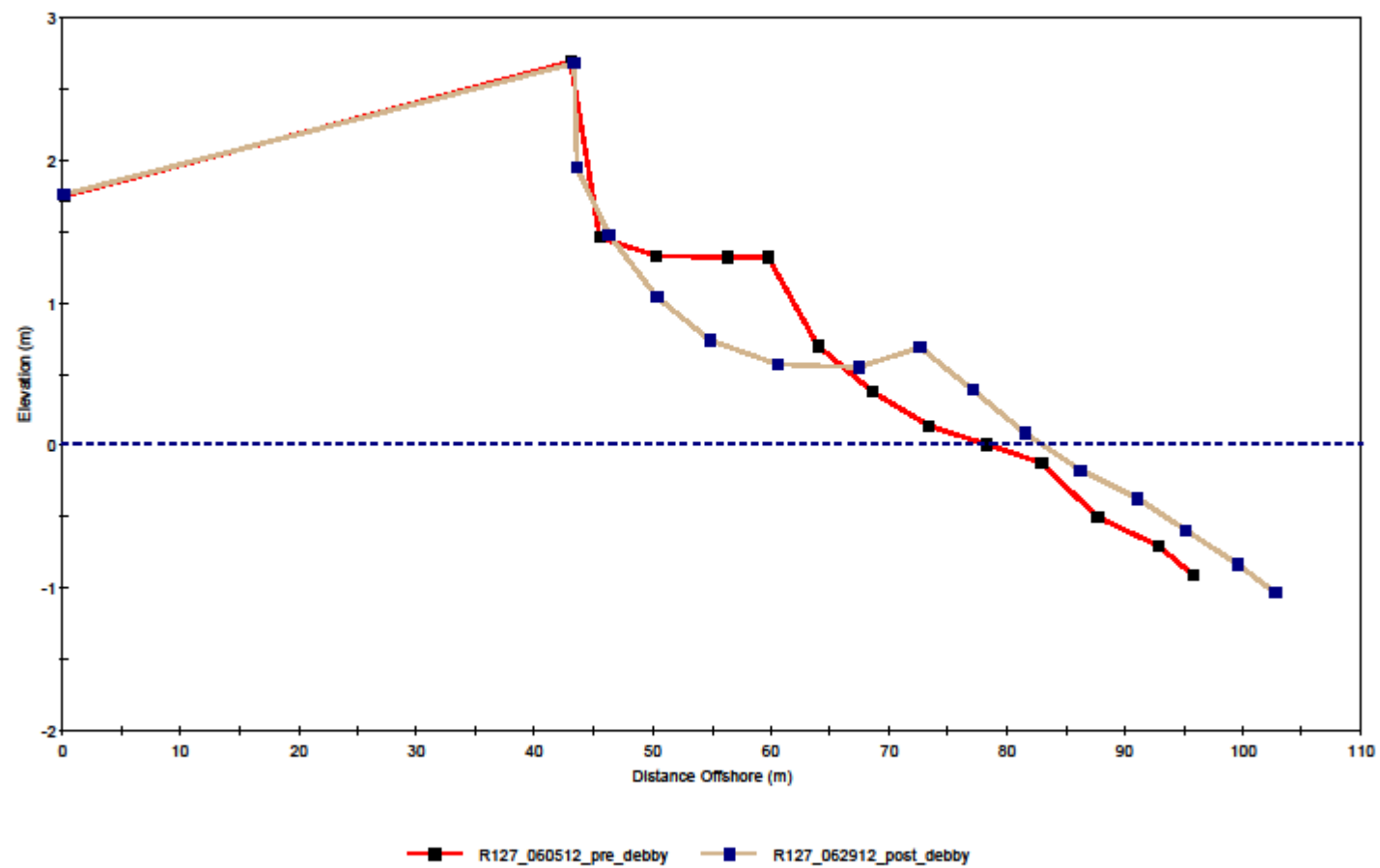


R124

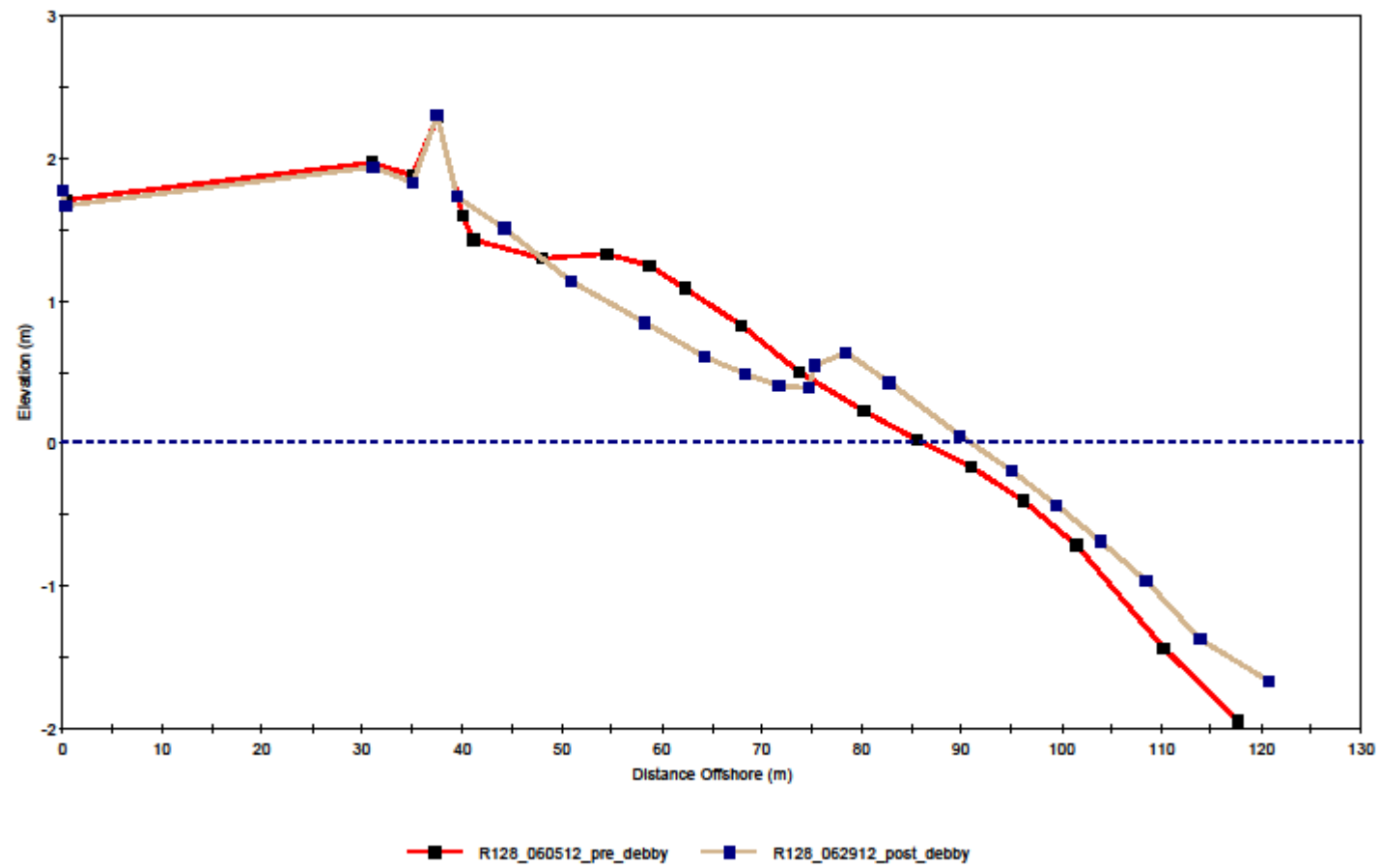


Treasure Island

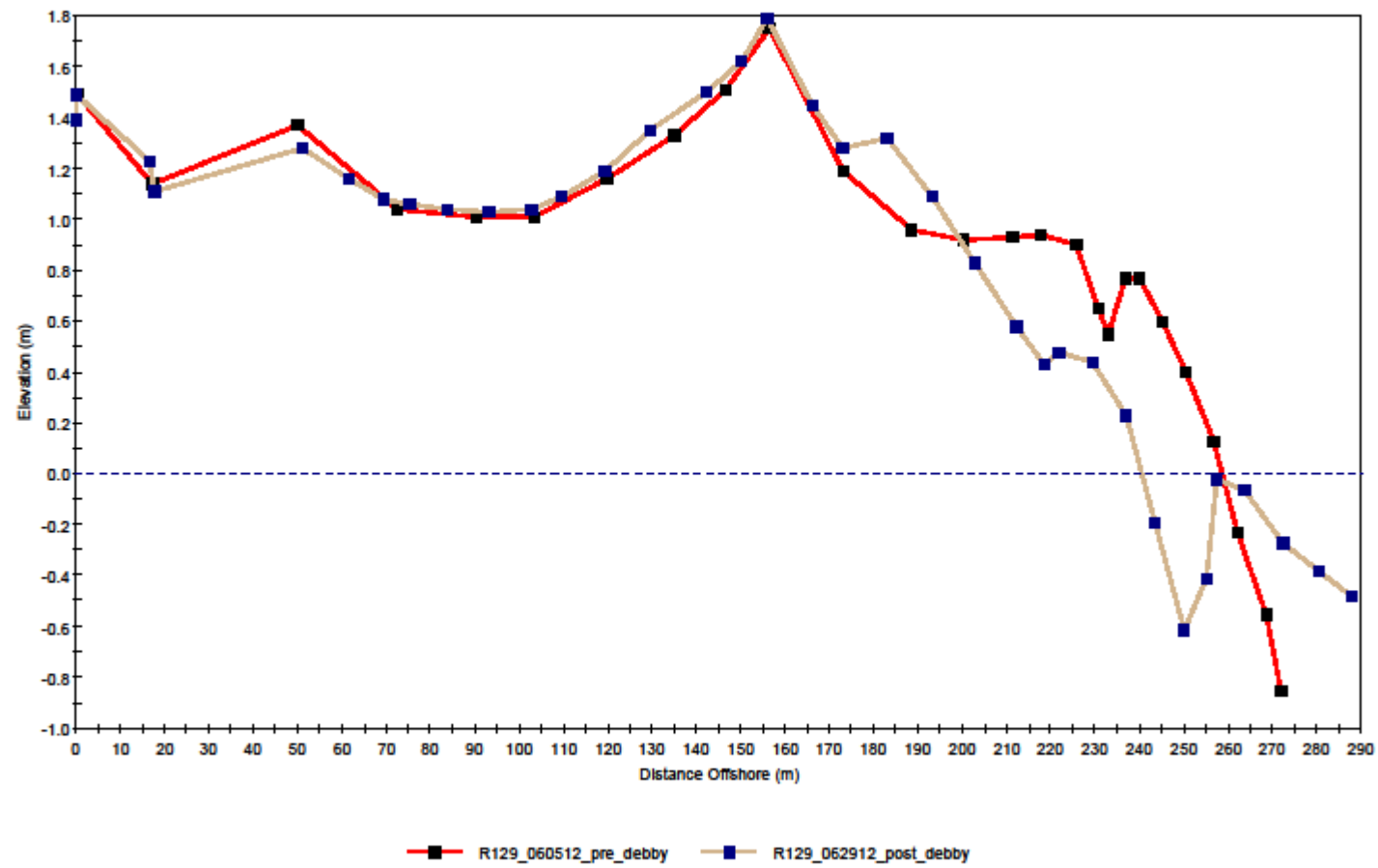
R127



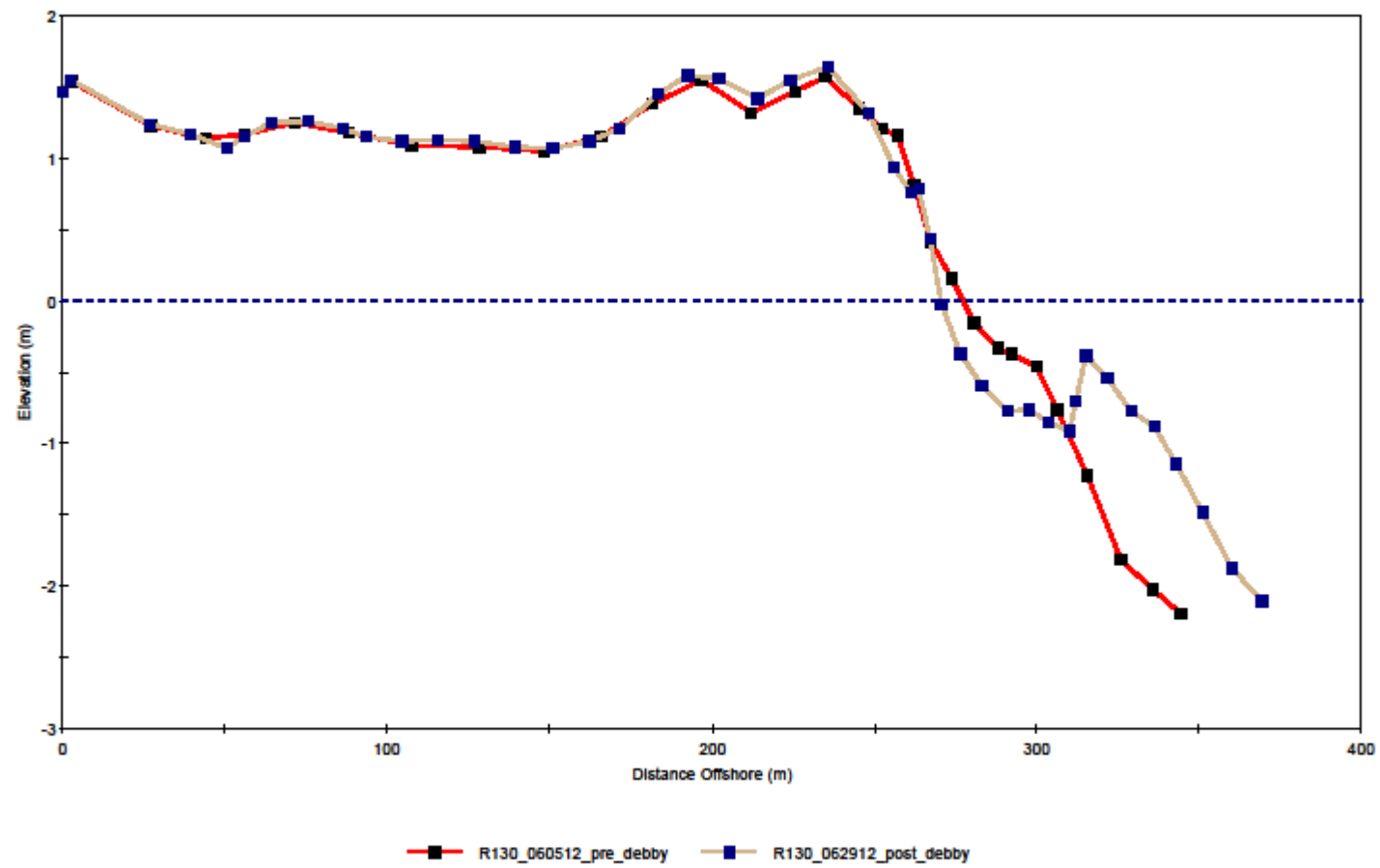
R128

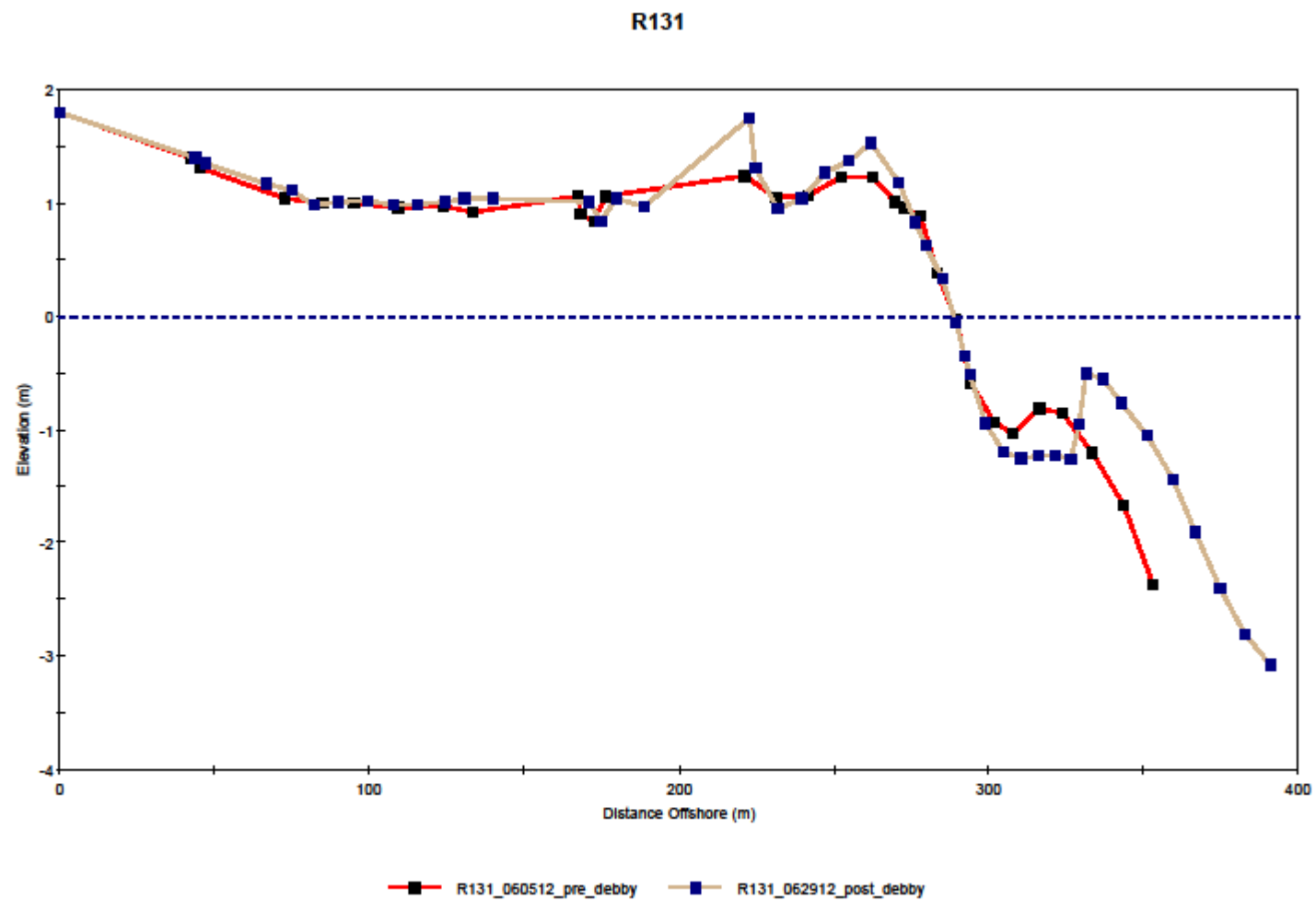


R129

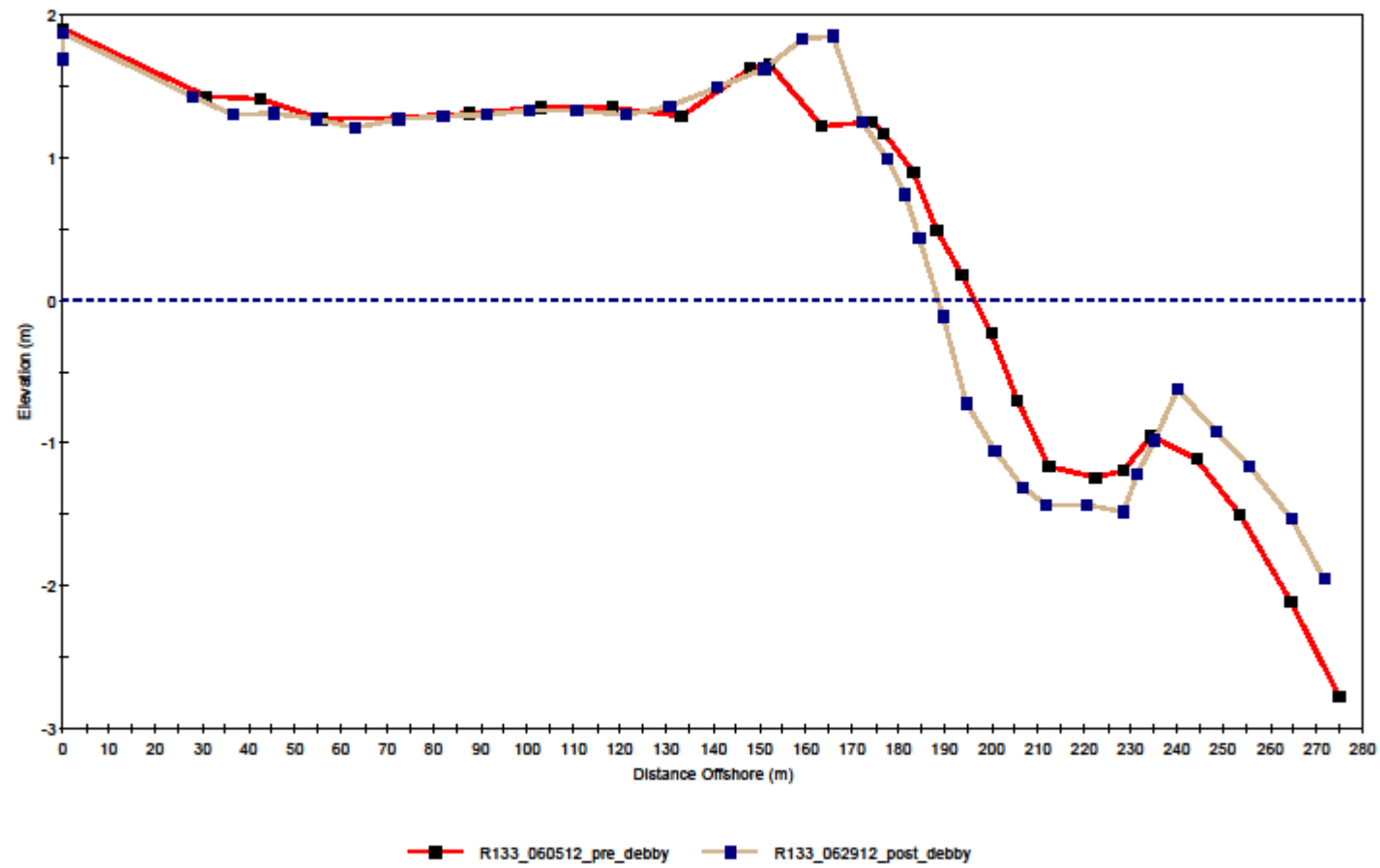


R130

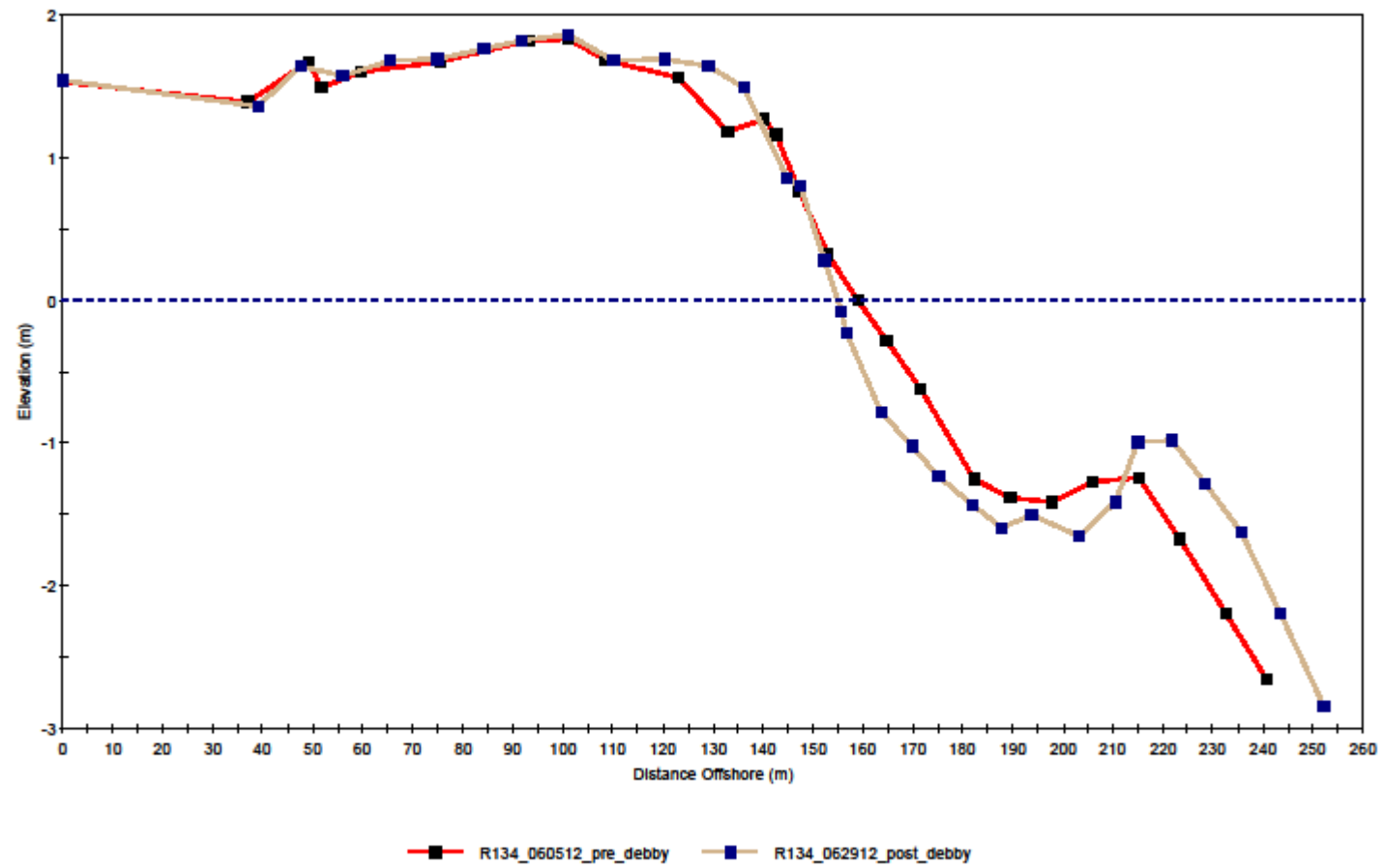




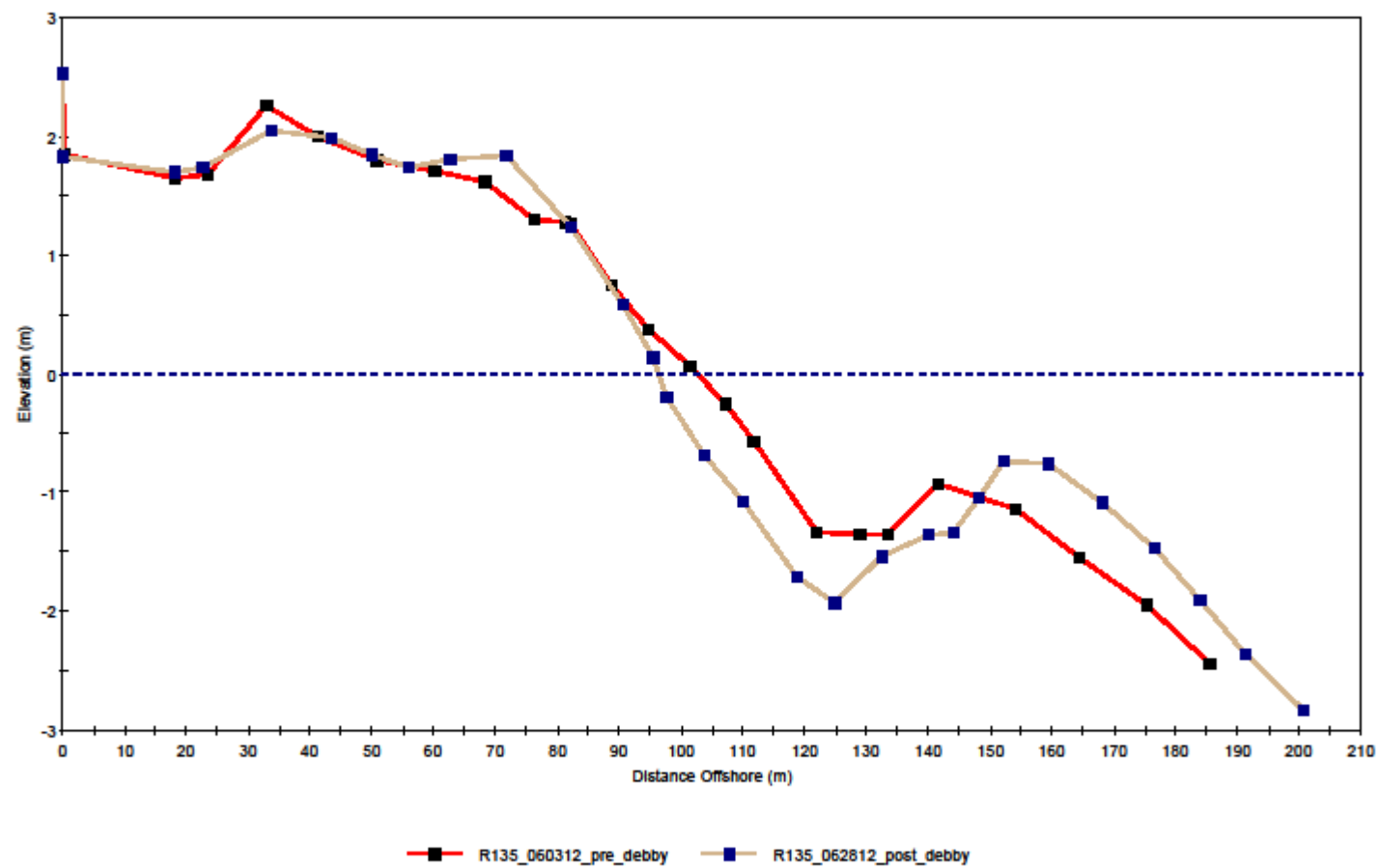
R133



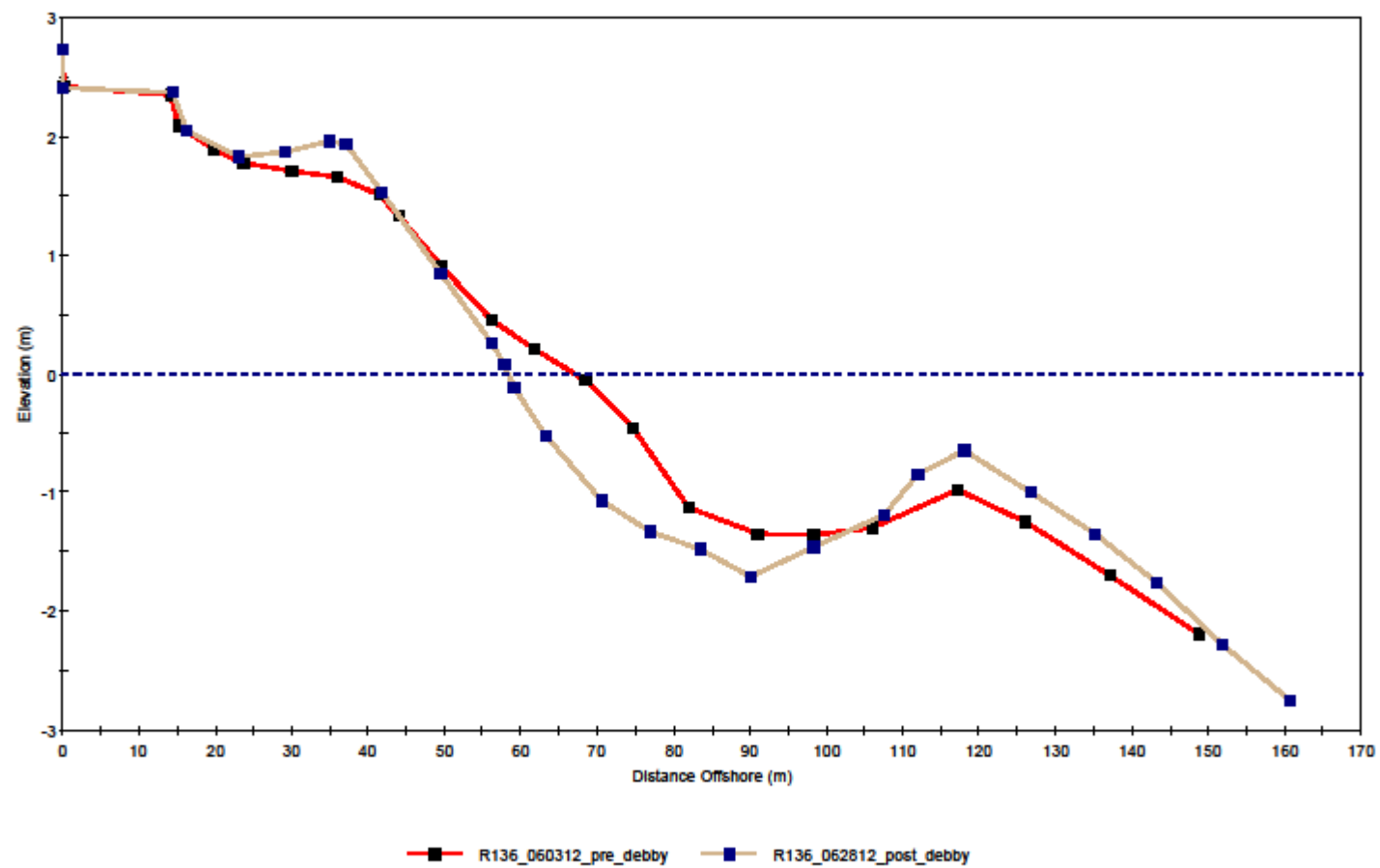
R134



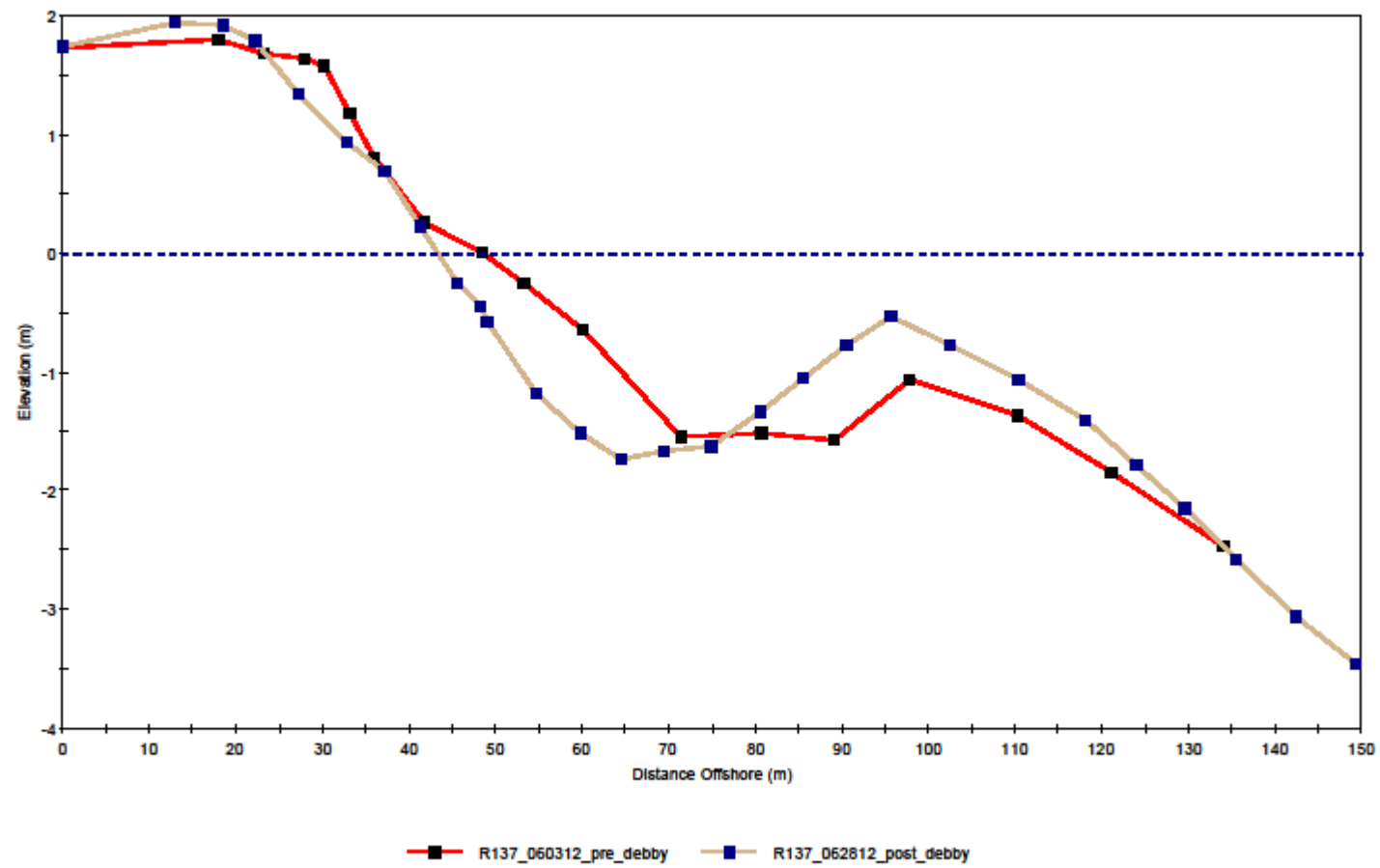
R135



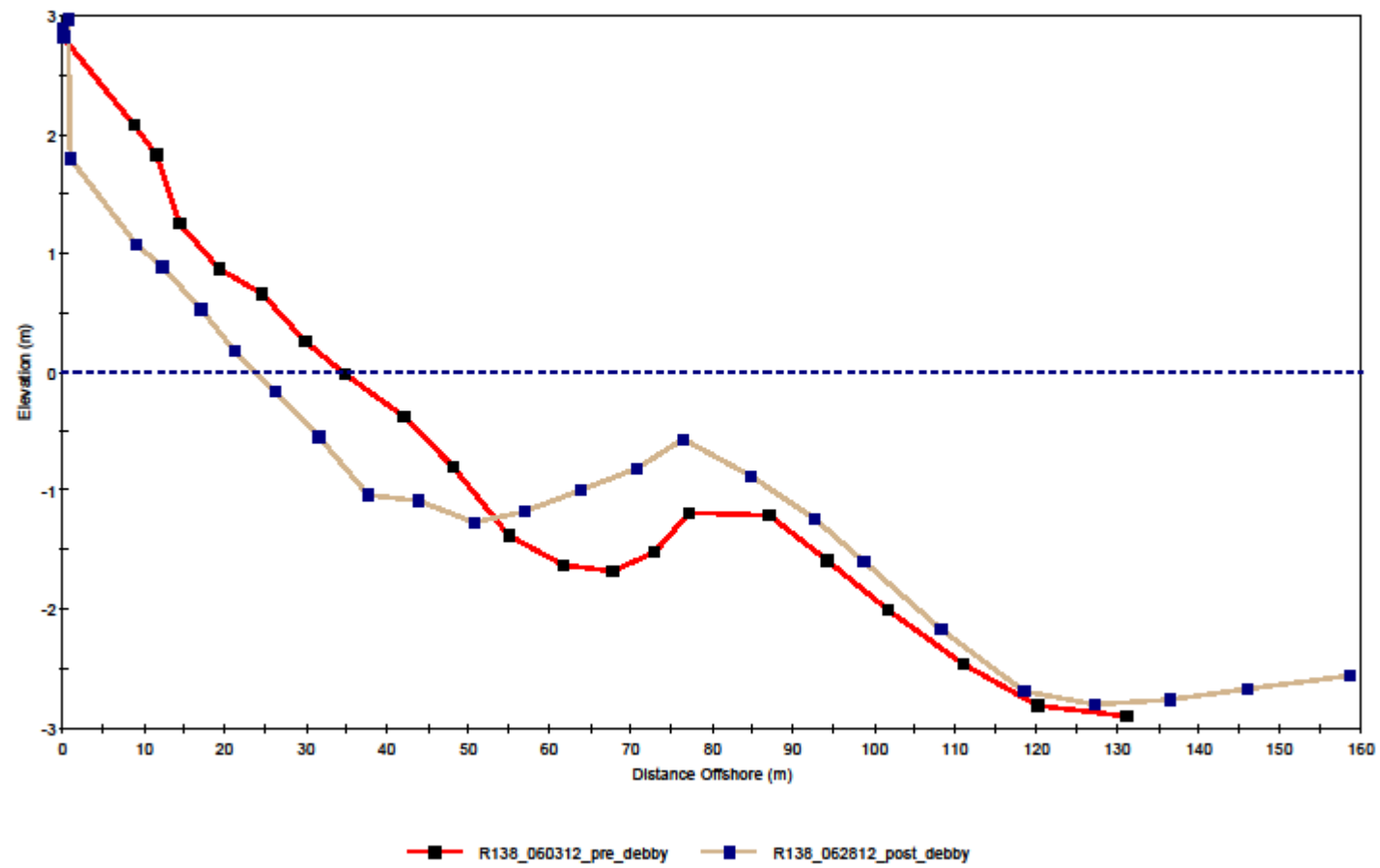
R136



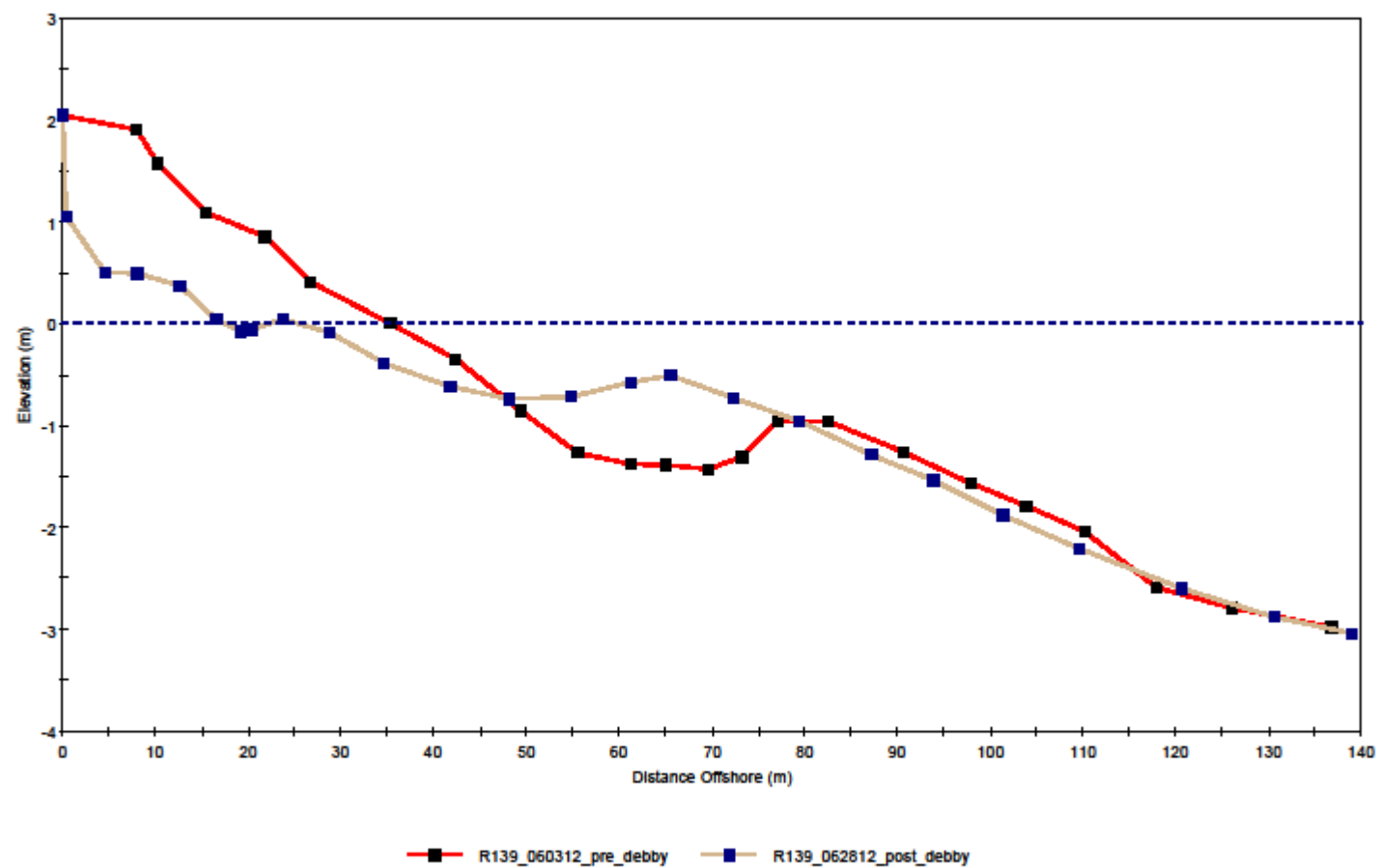
R137



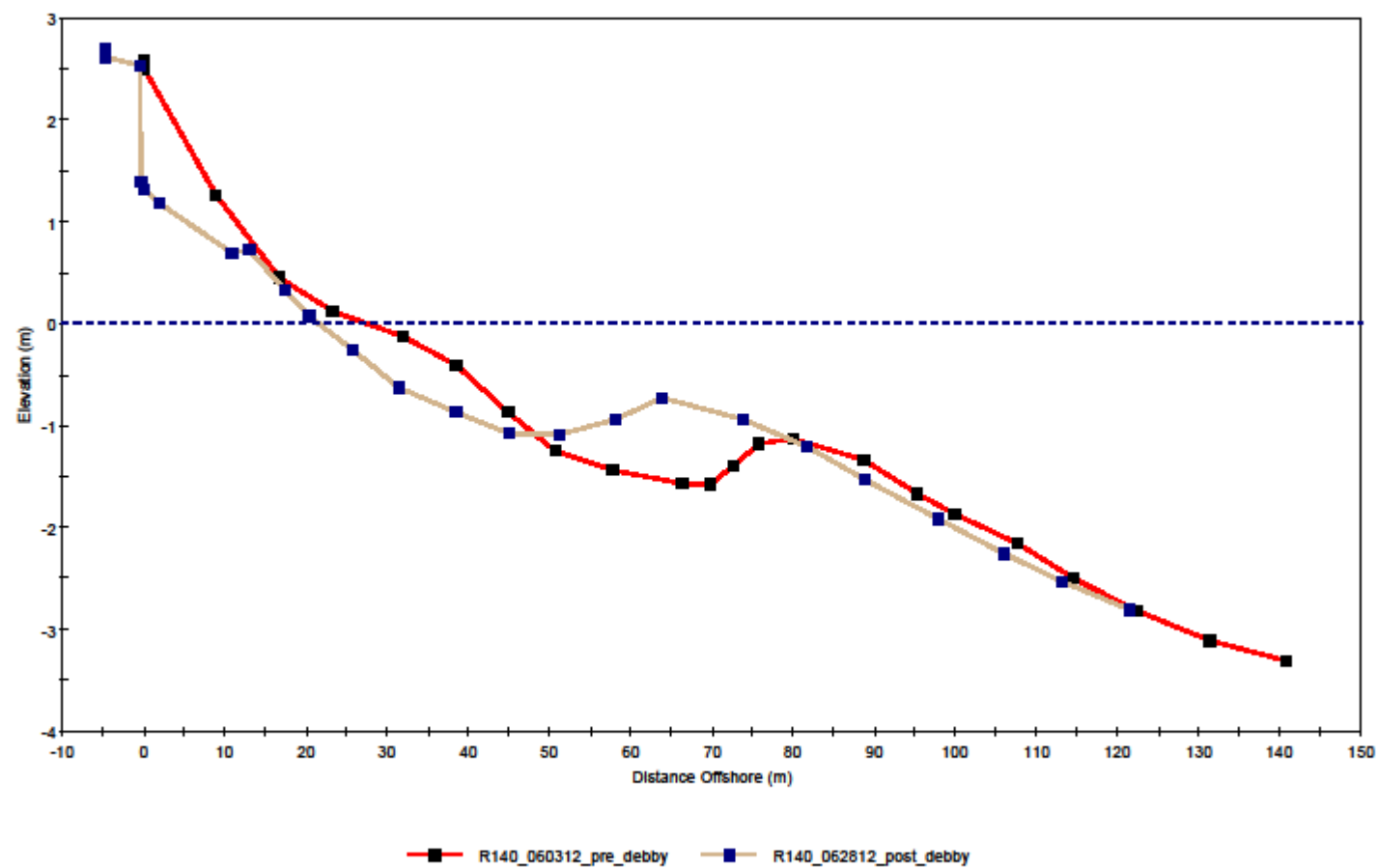
R138



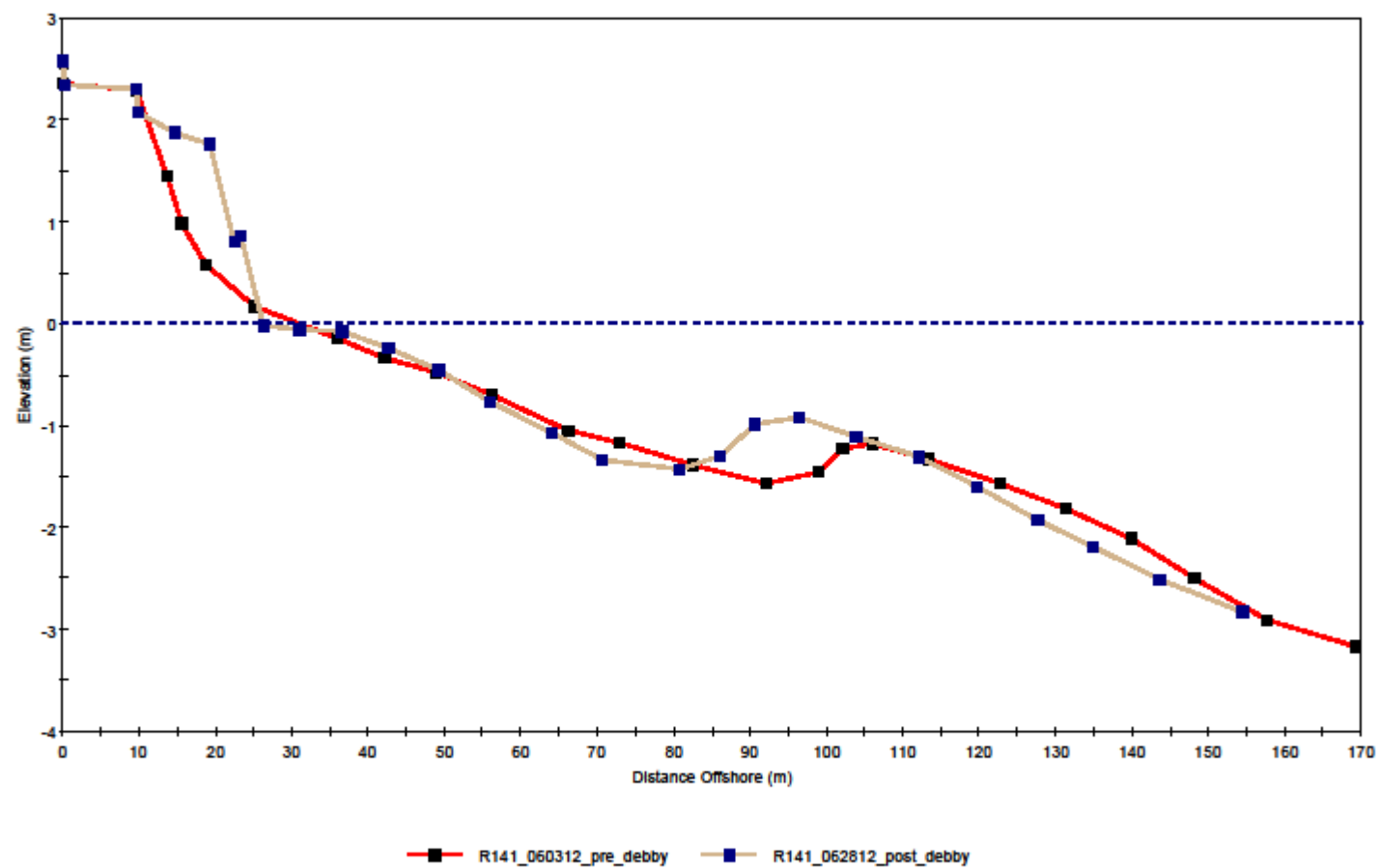
R139



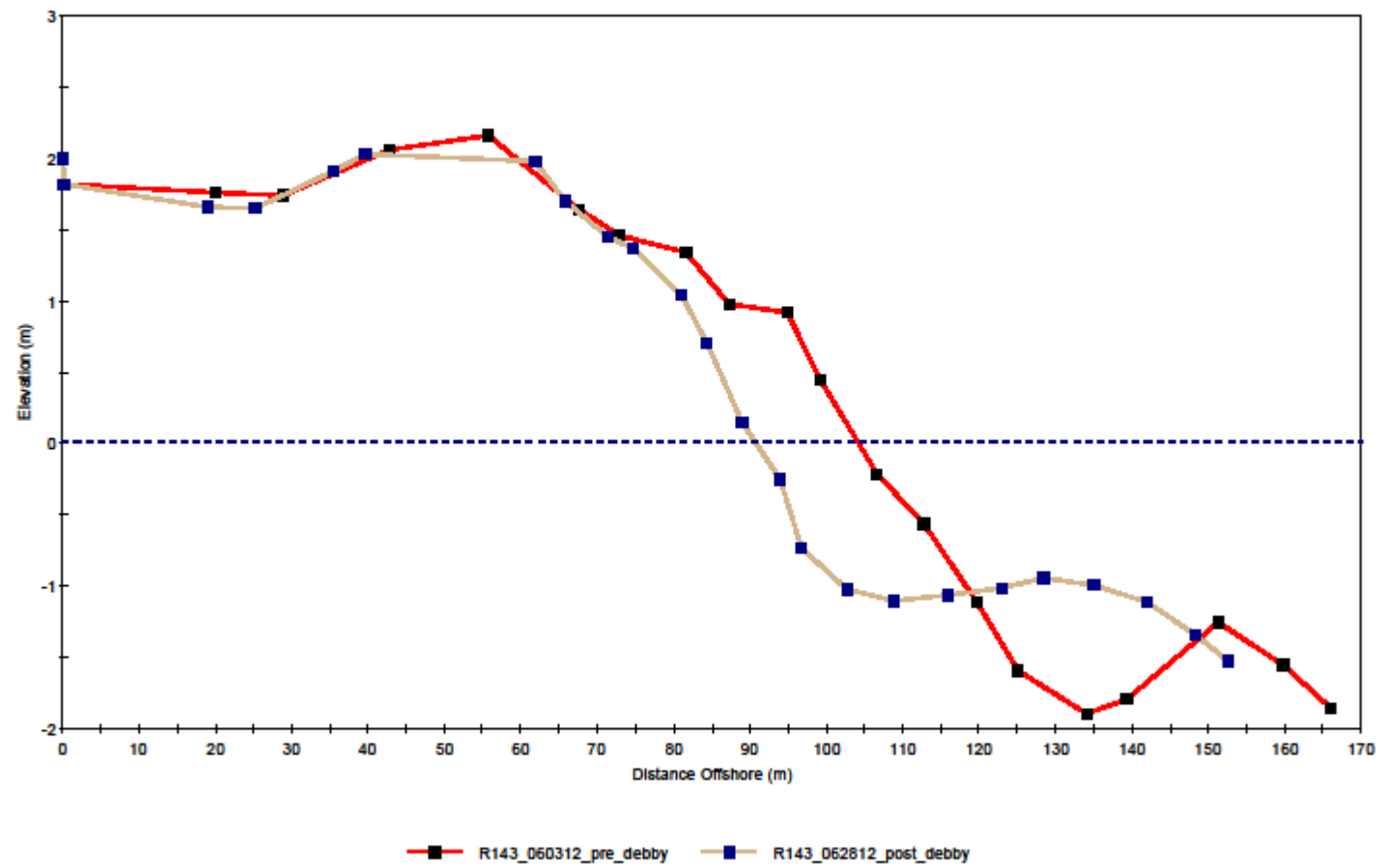
R140



R141

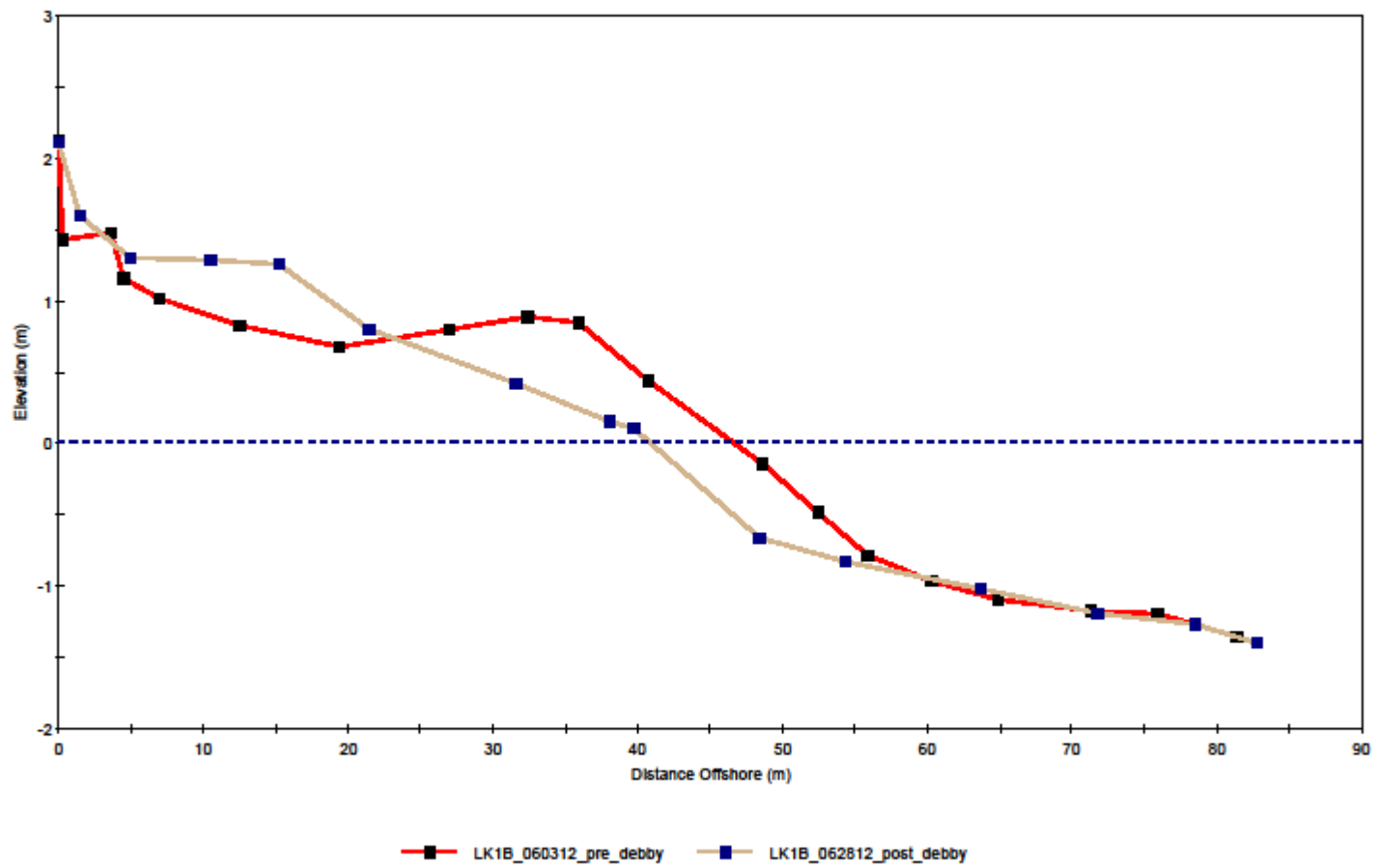


R143

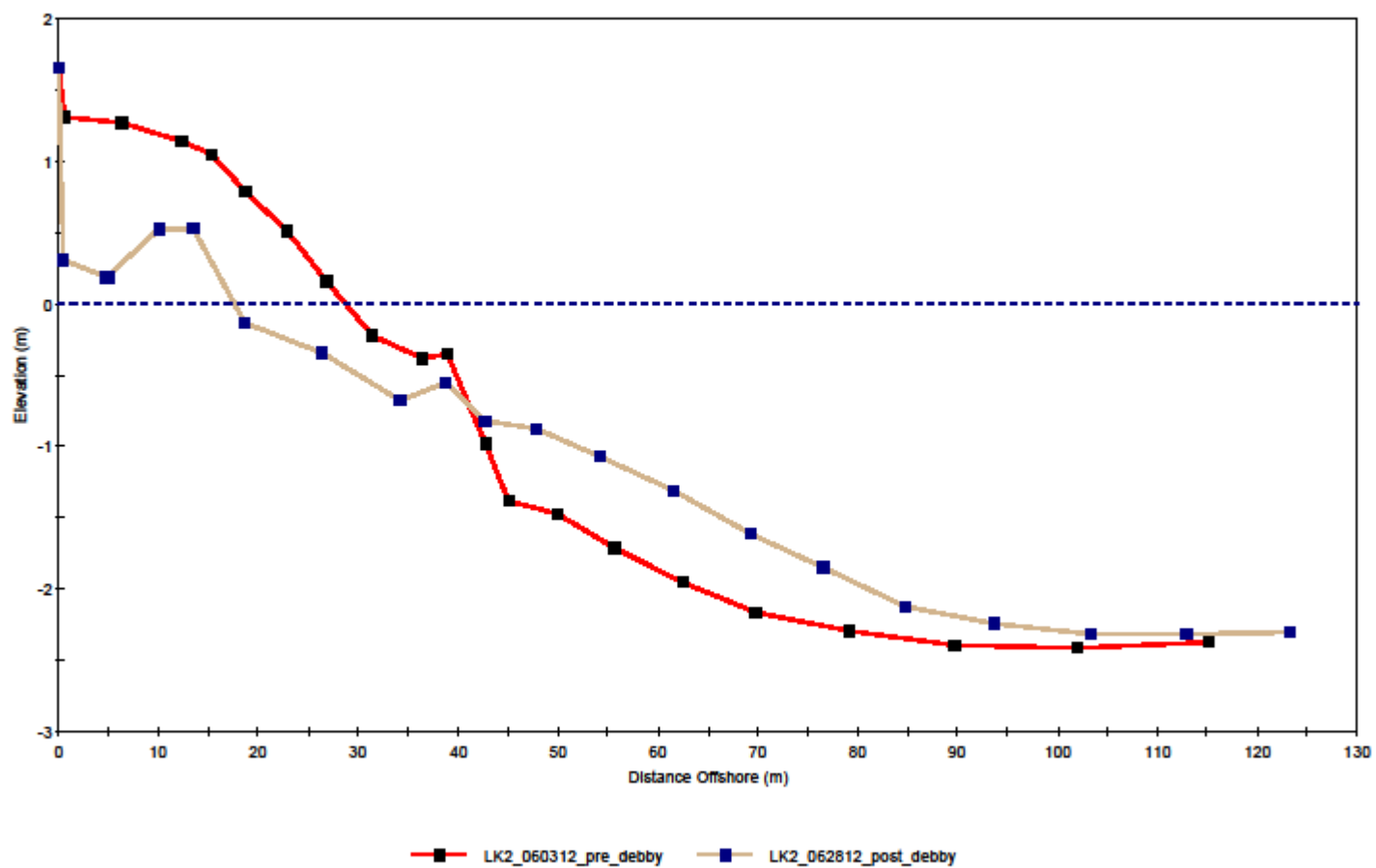


Long Key

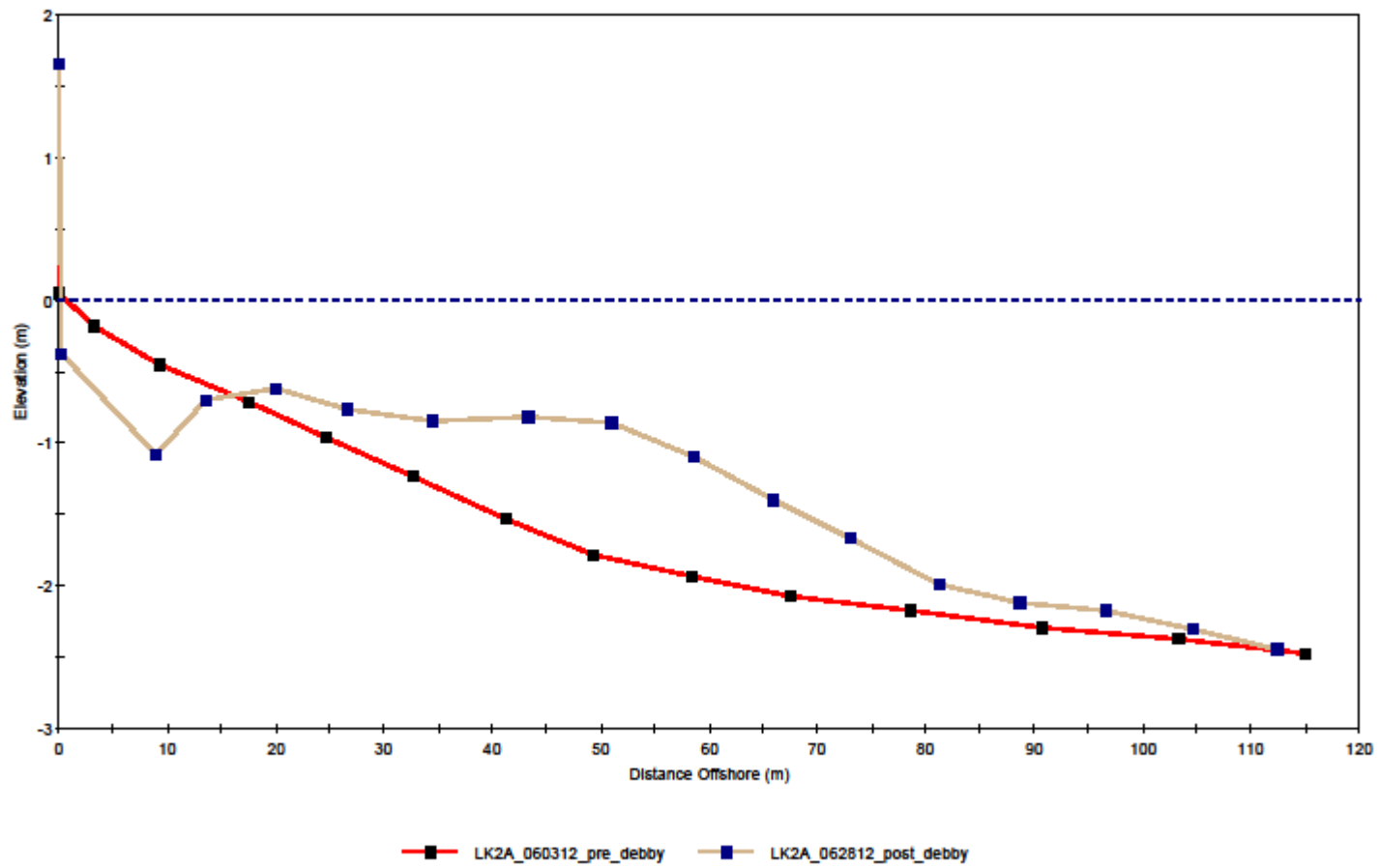
LK1B



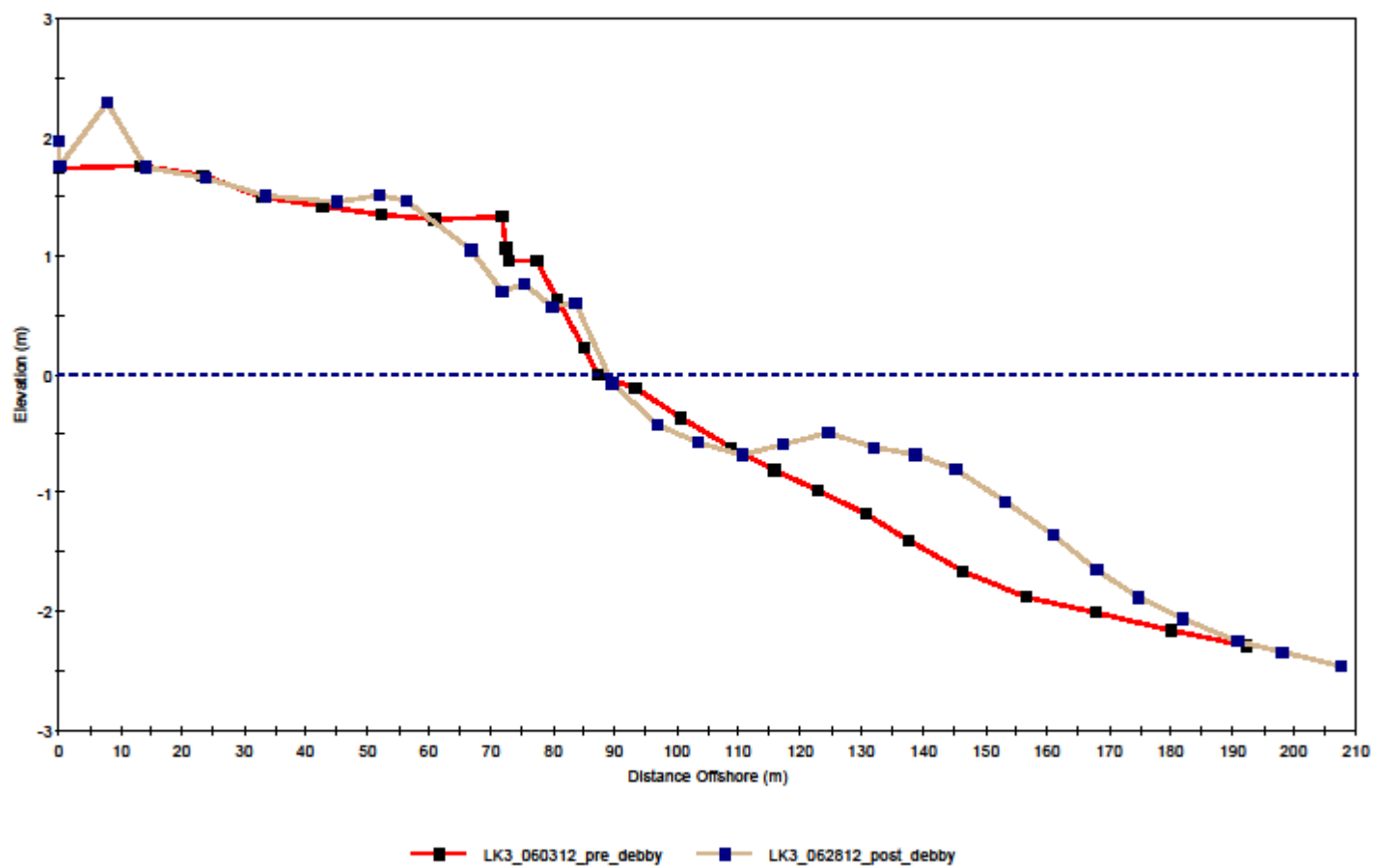
LK2



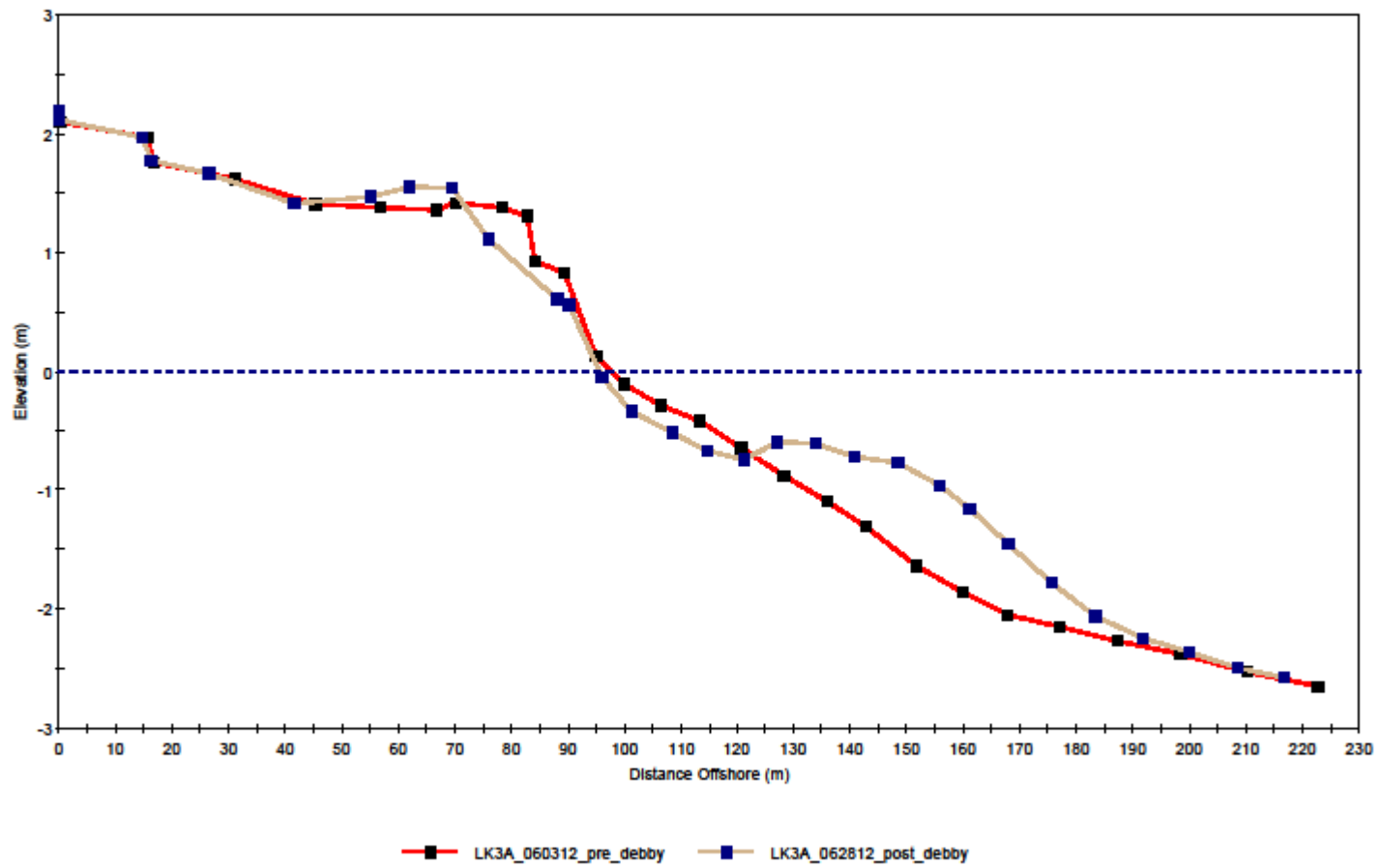
LK2A



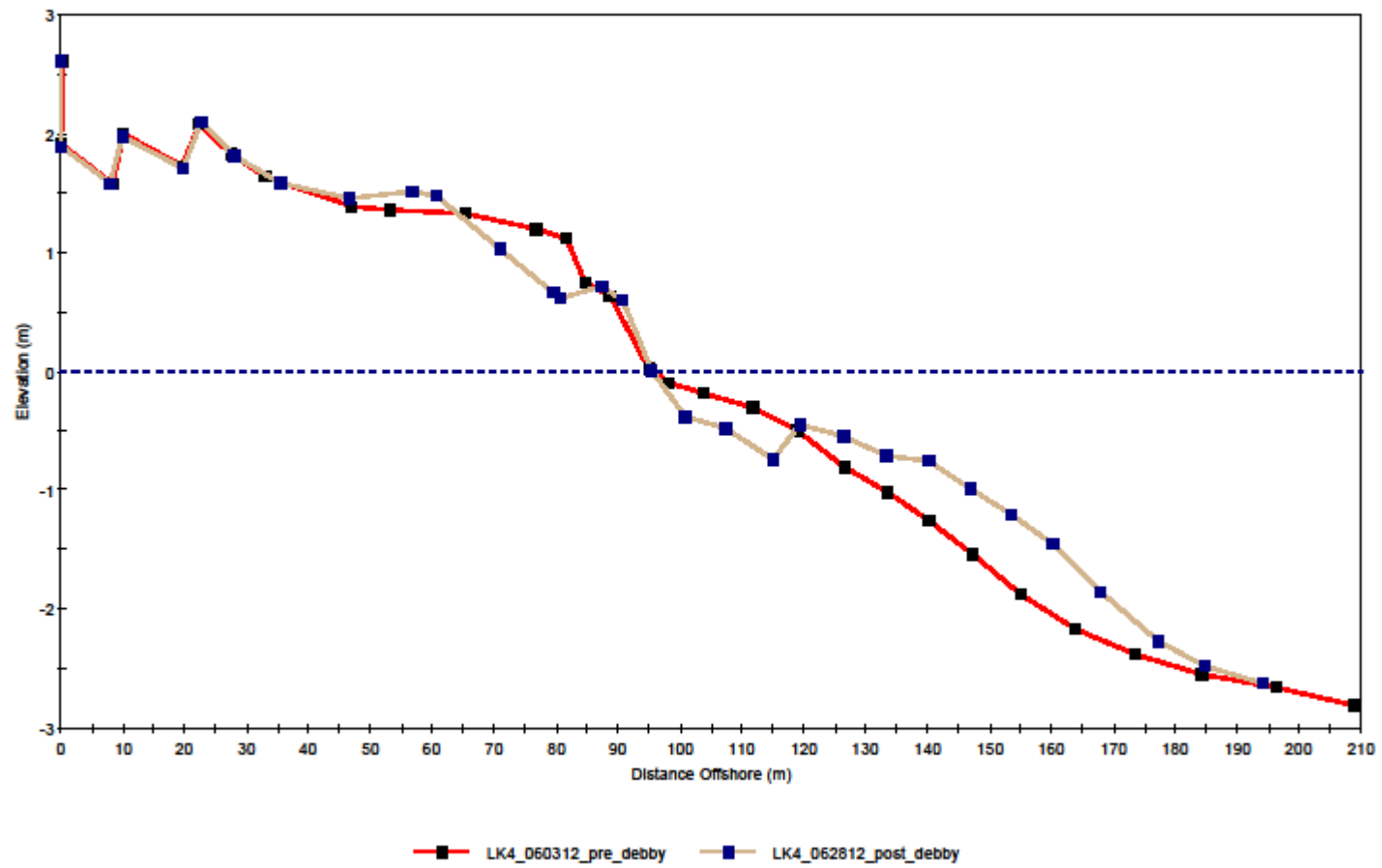
LK3



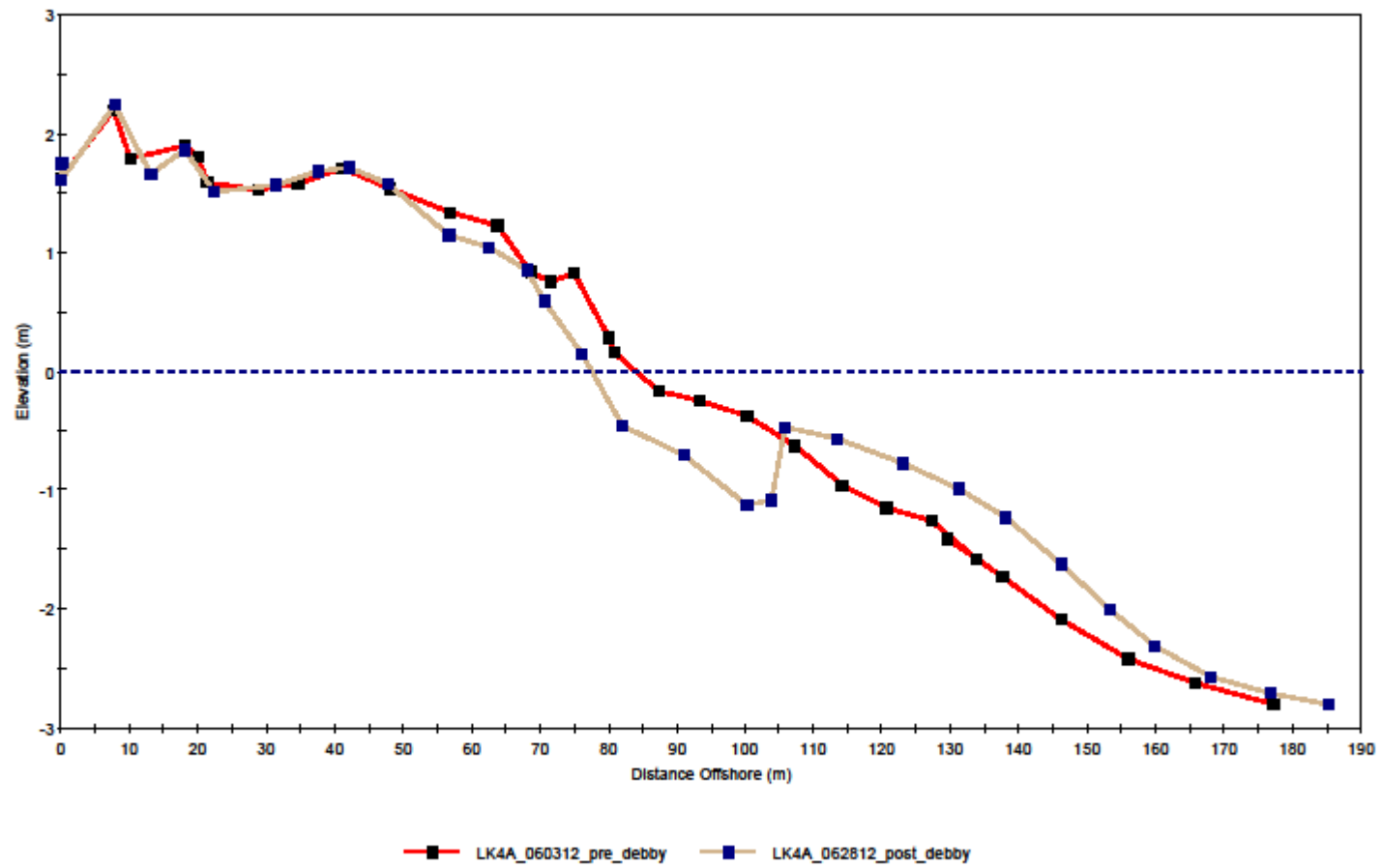
LK3A



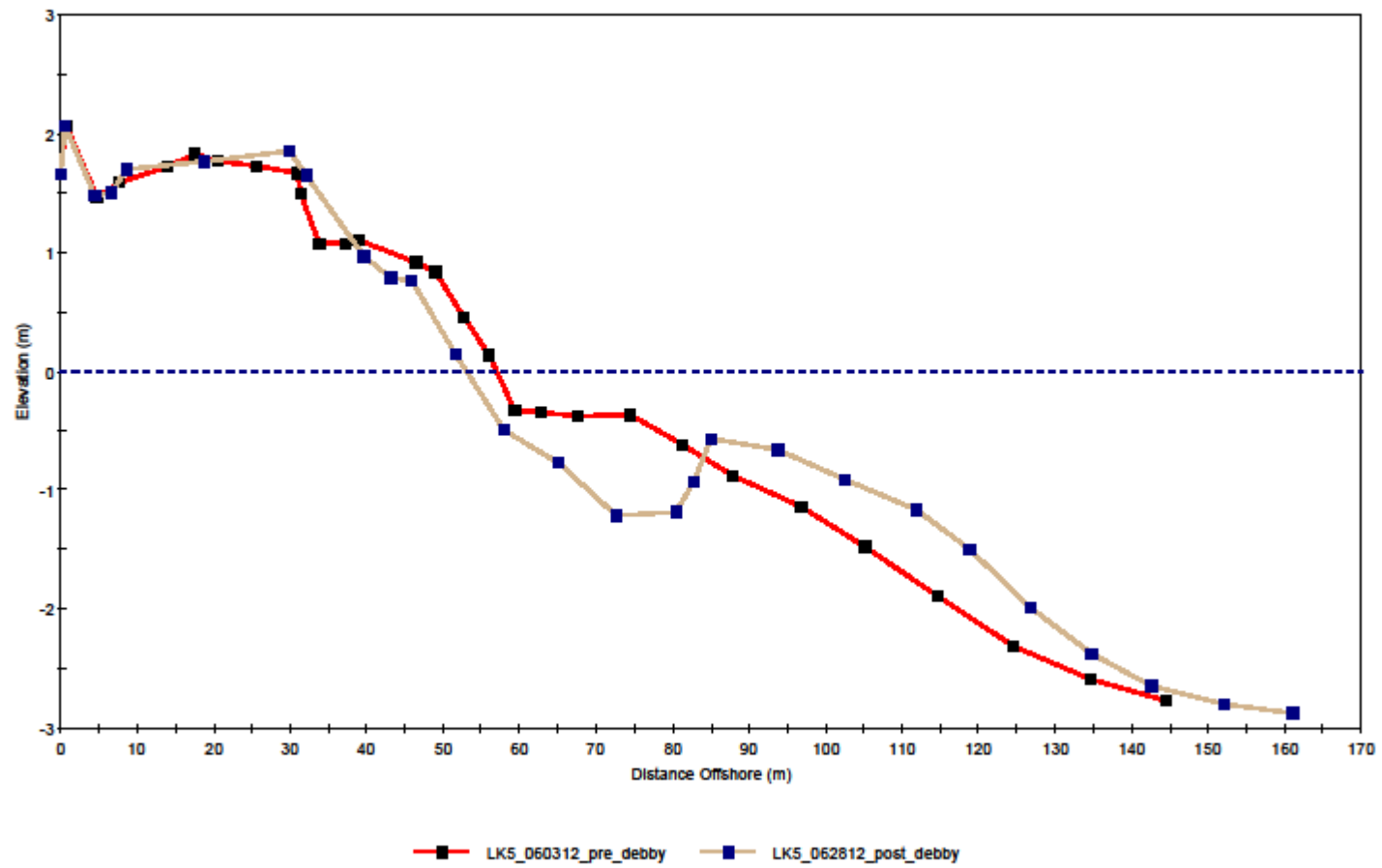
LK4



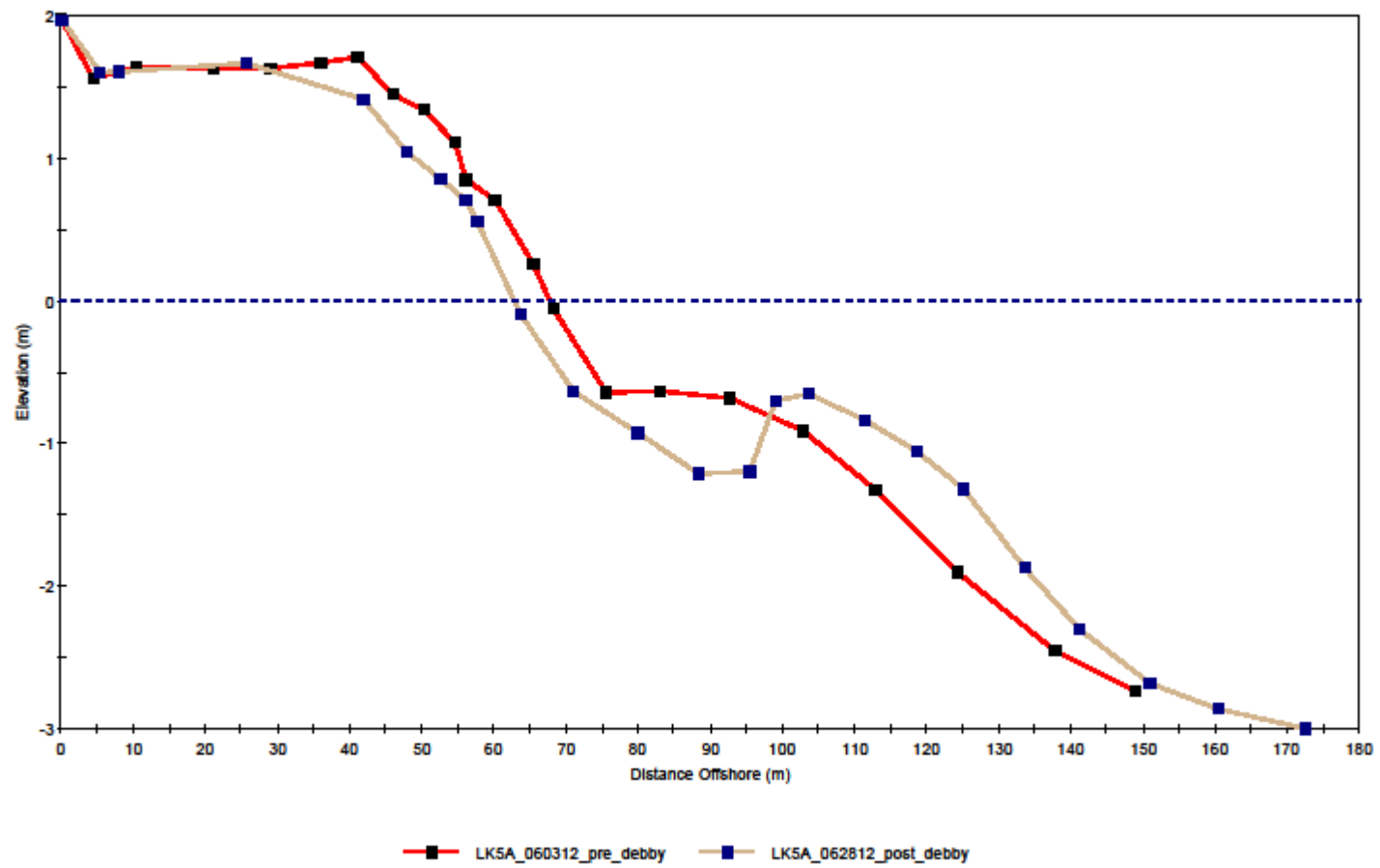
LK4A



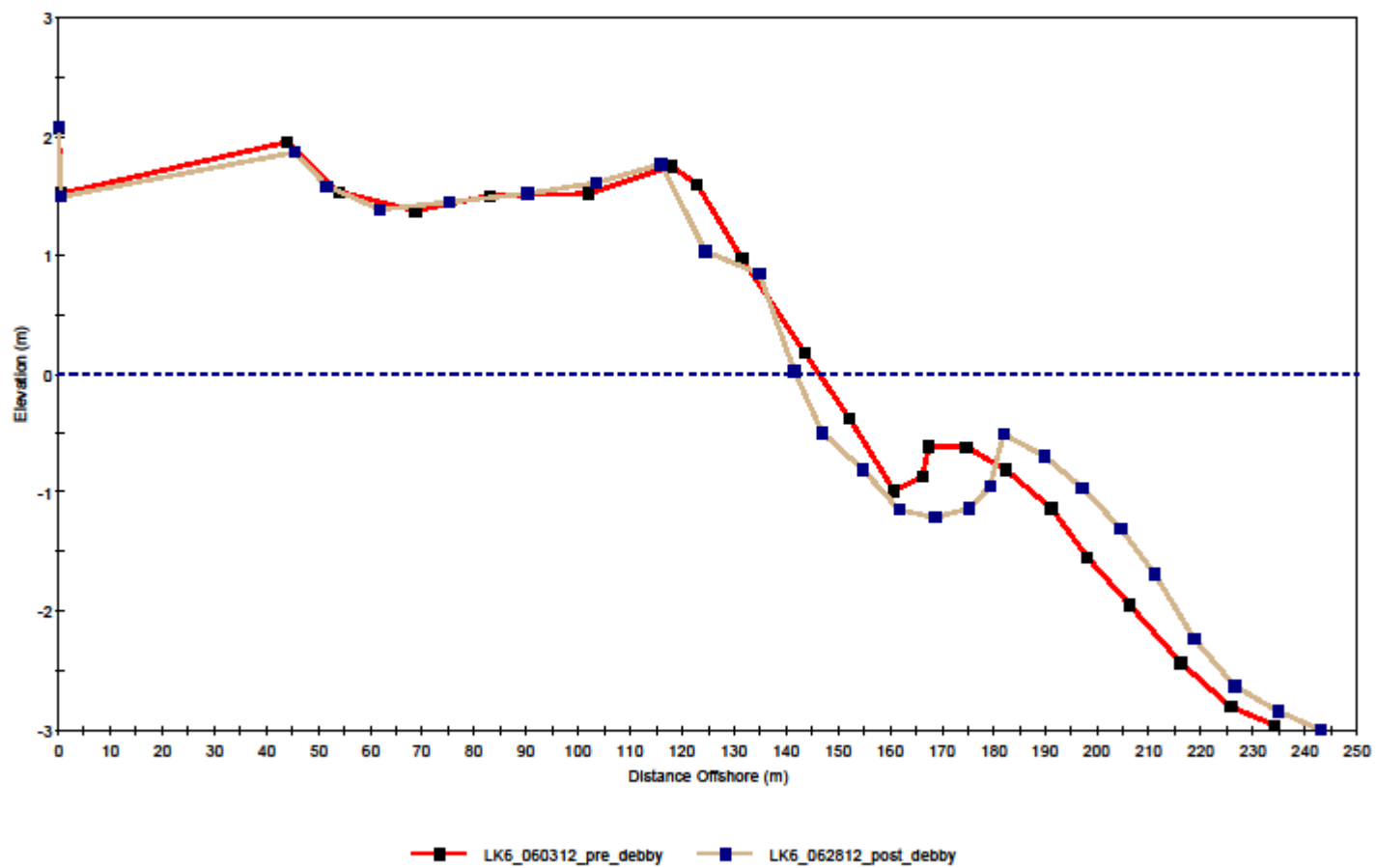
LK5



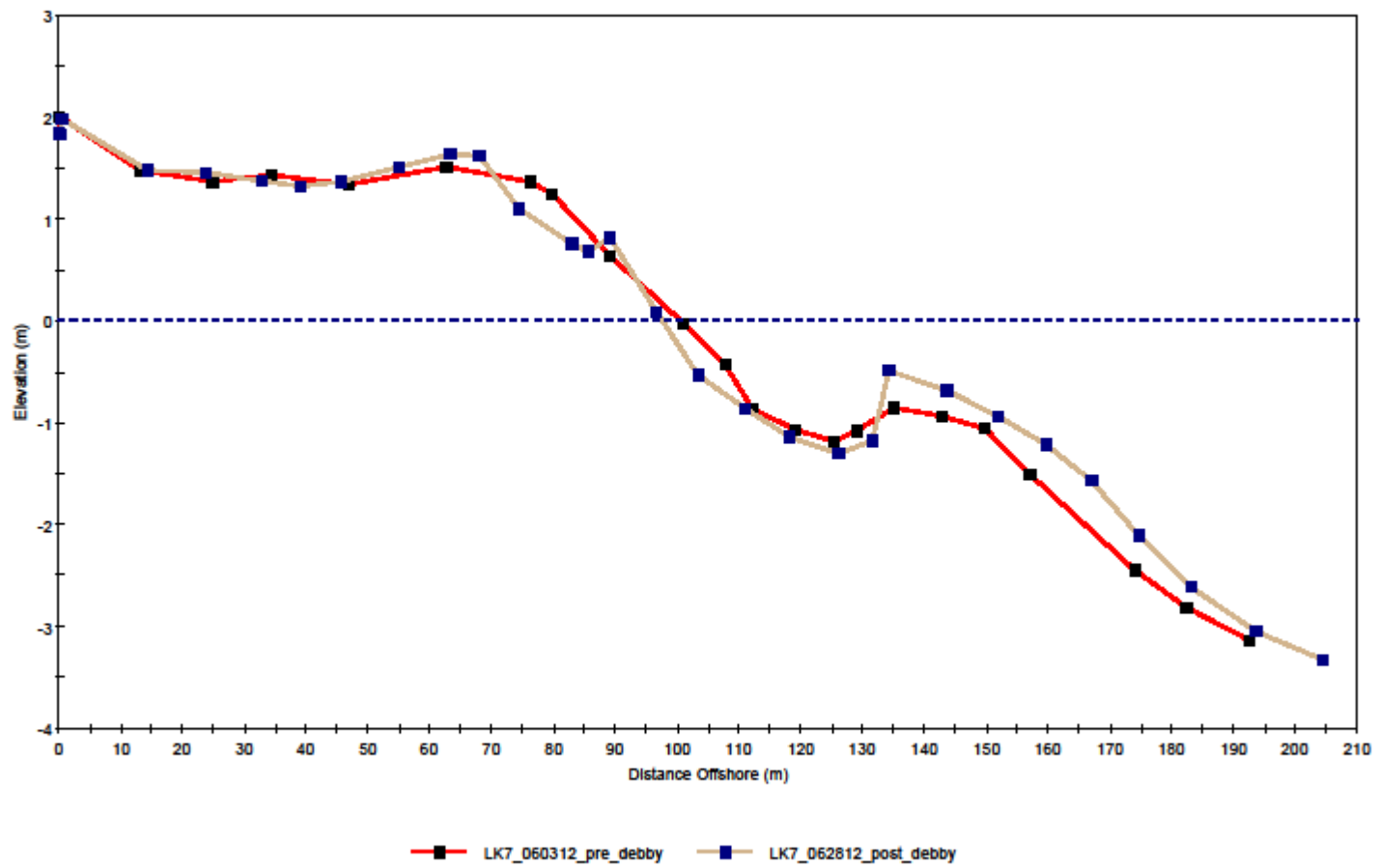
LK5A



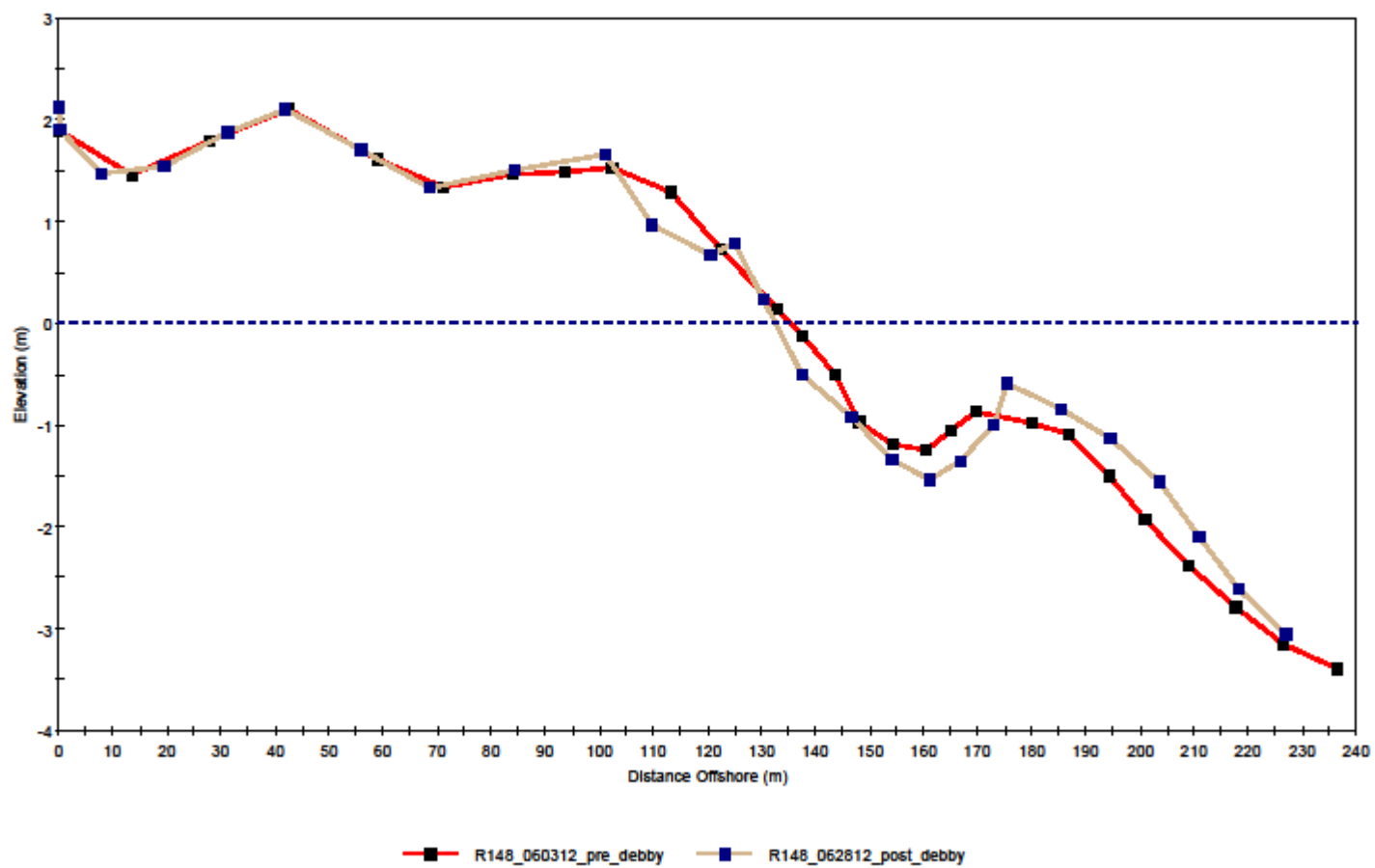
LK6



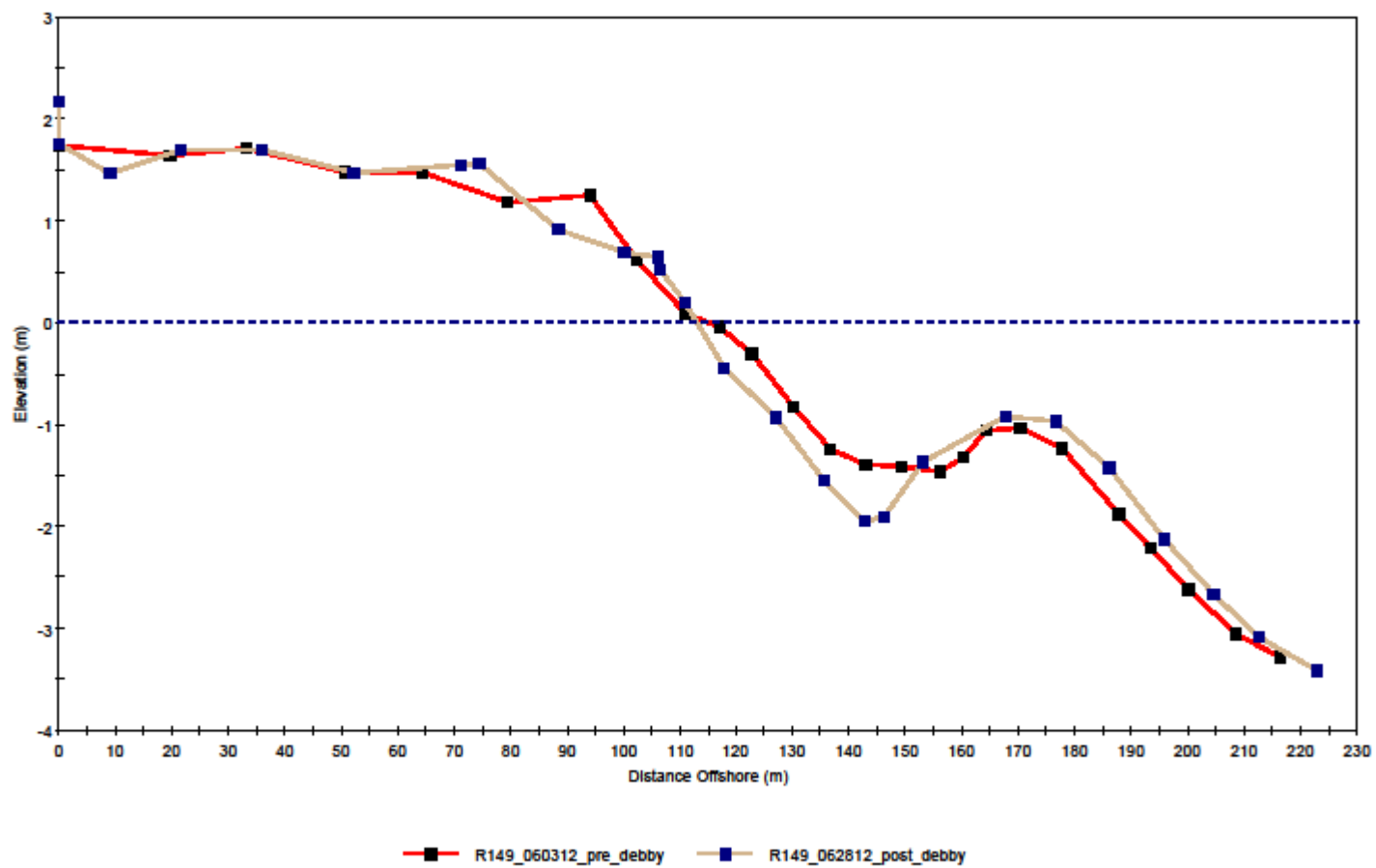
LK7



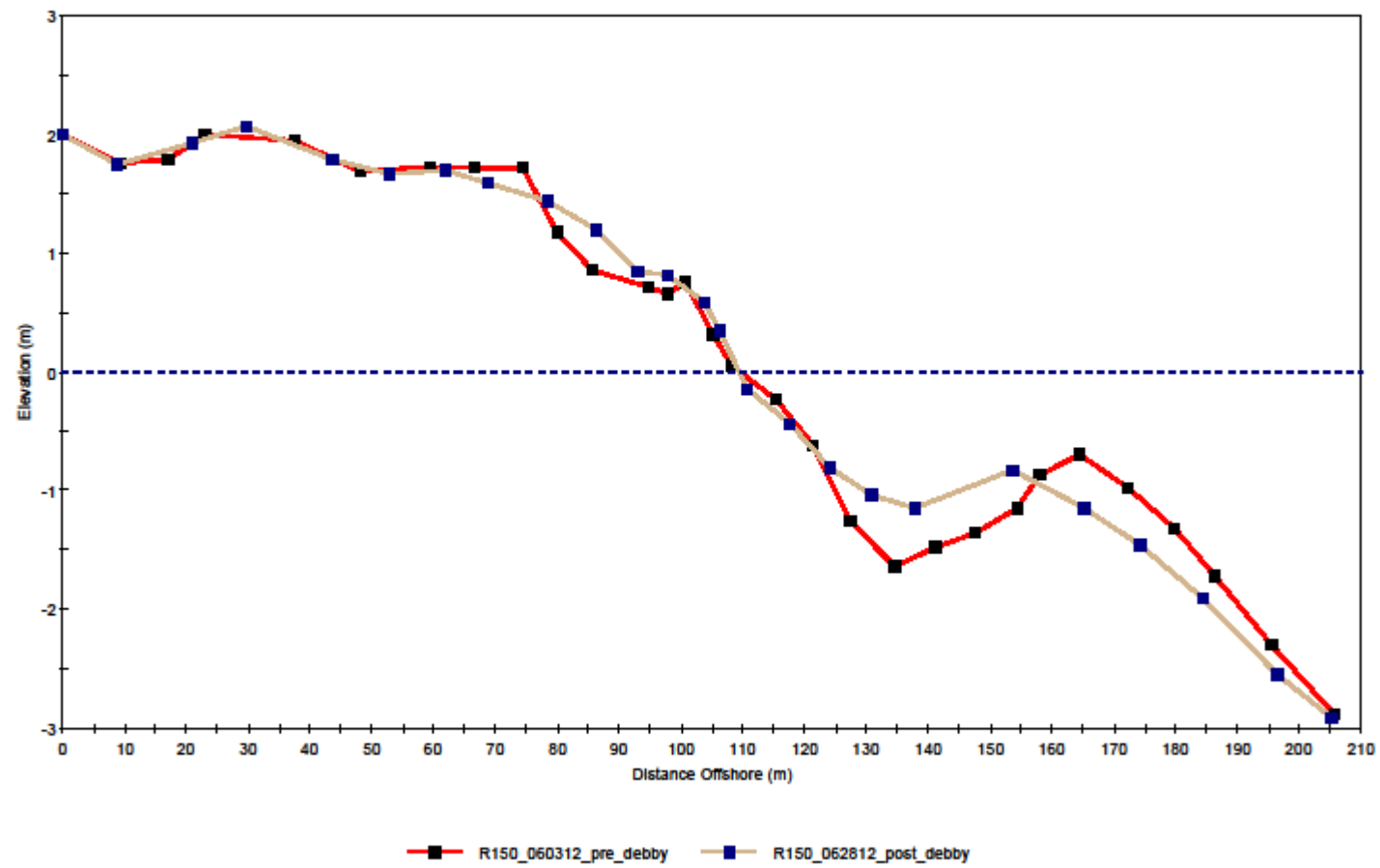
R148



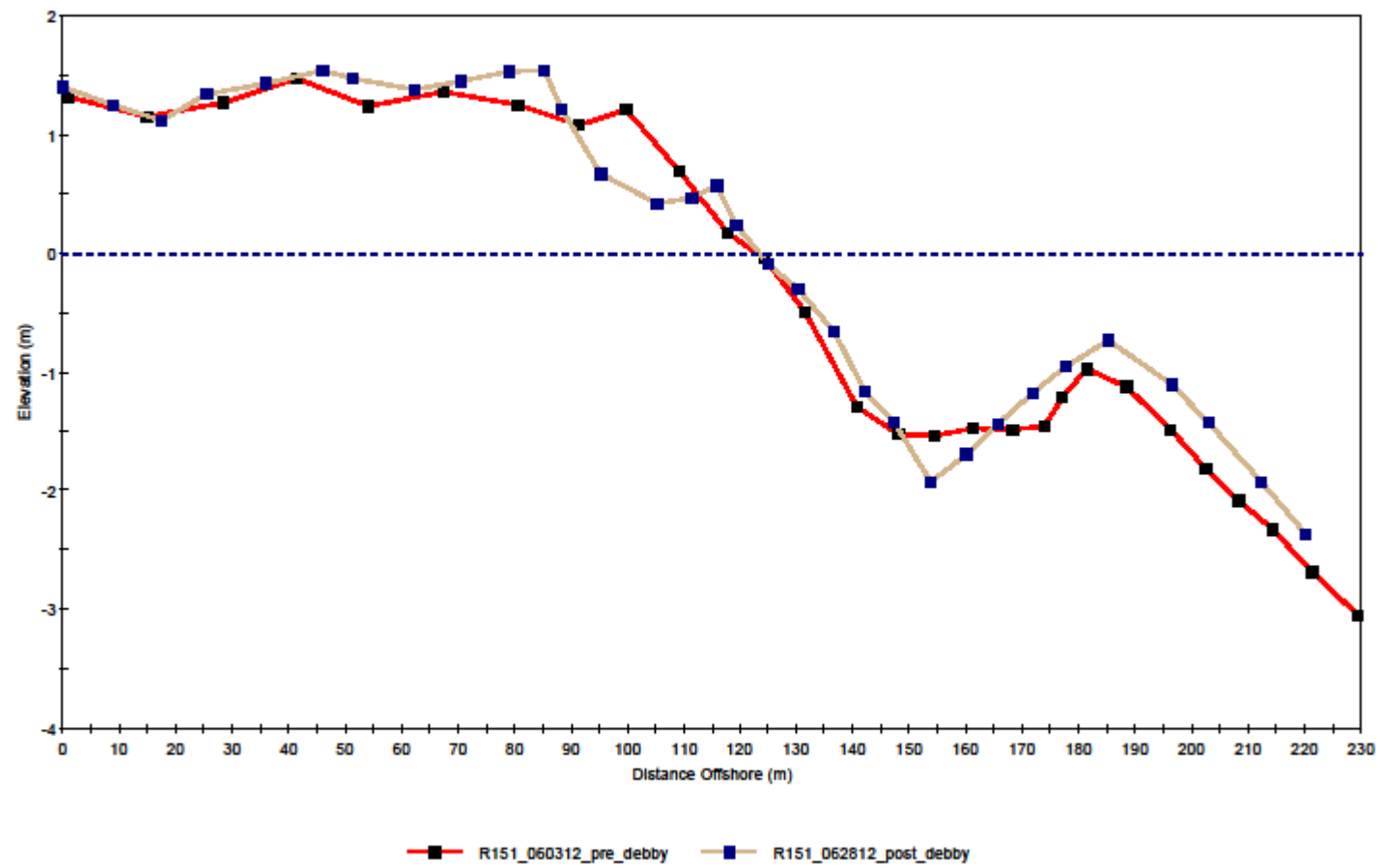
R149



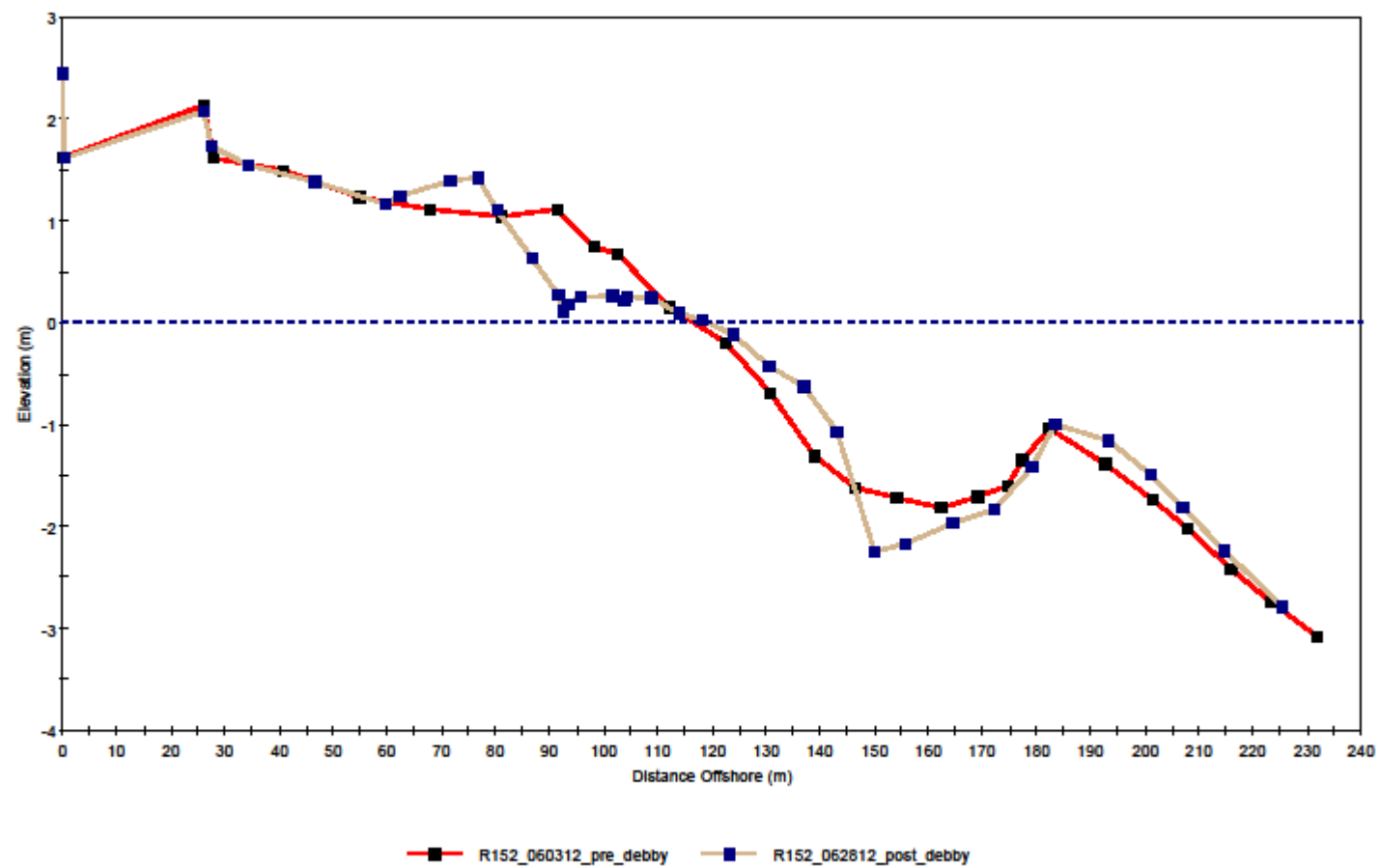
R150



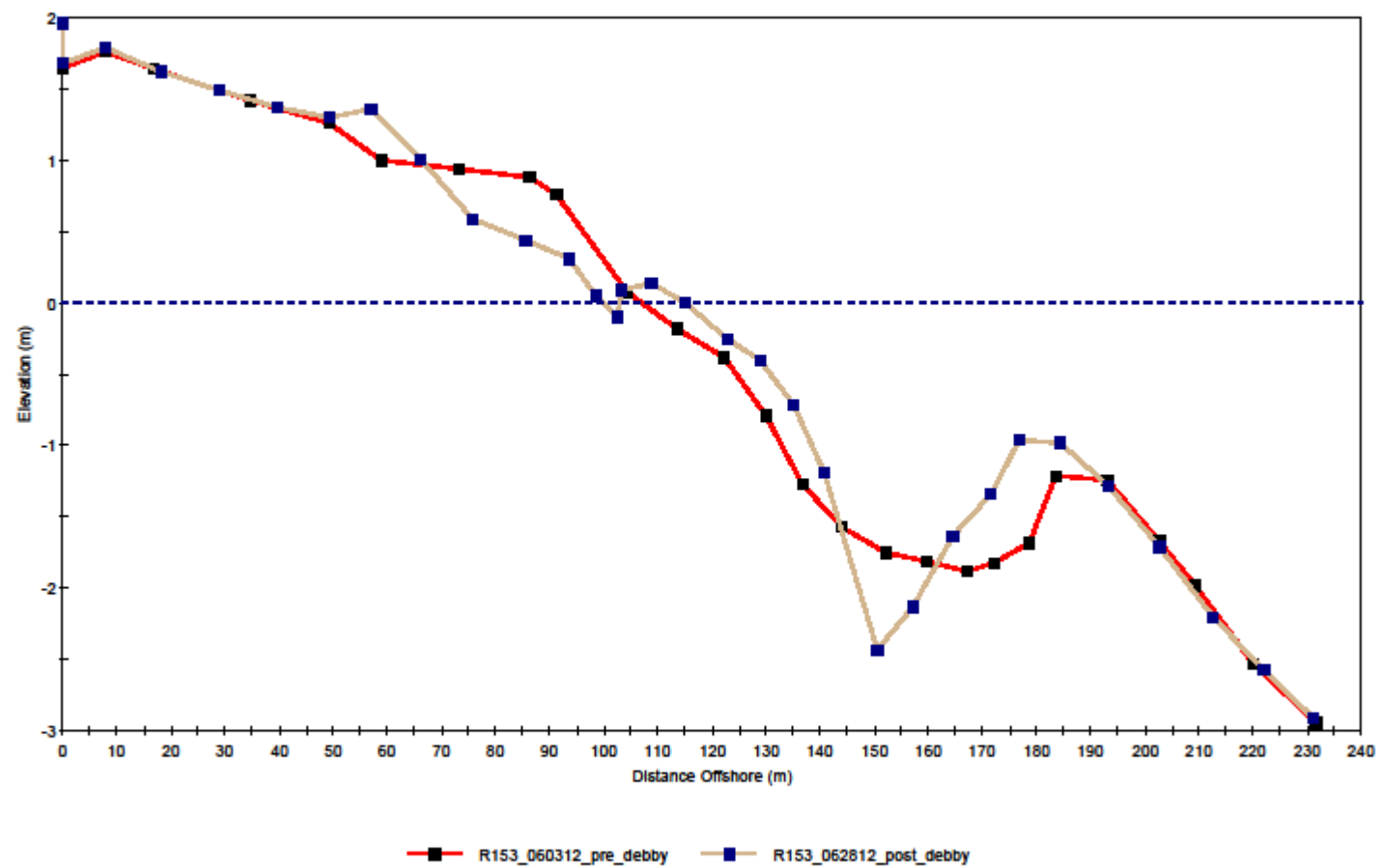
R151



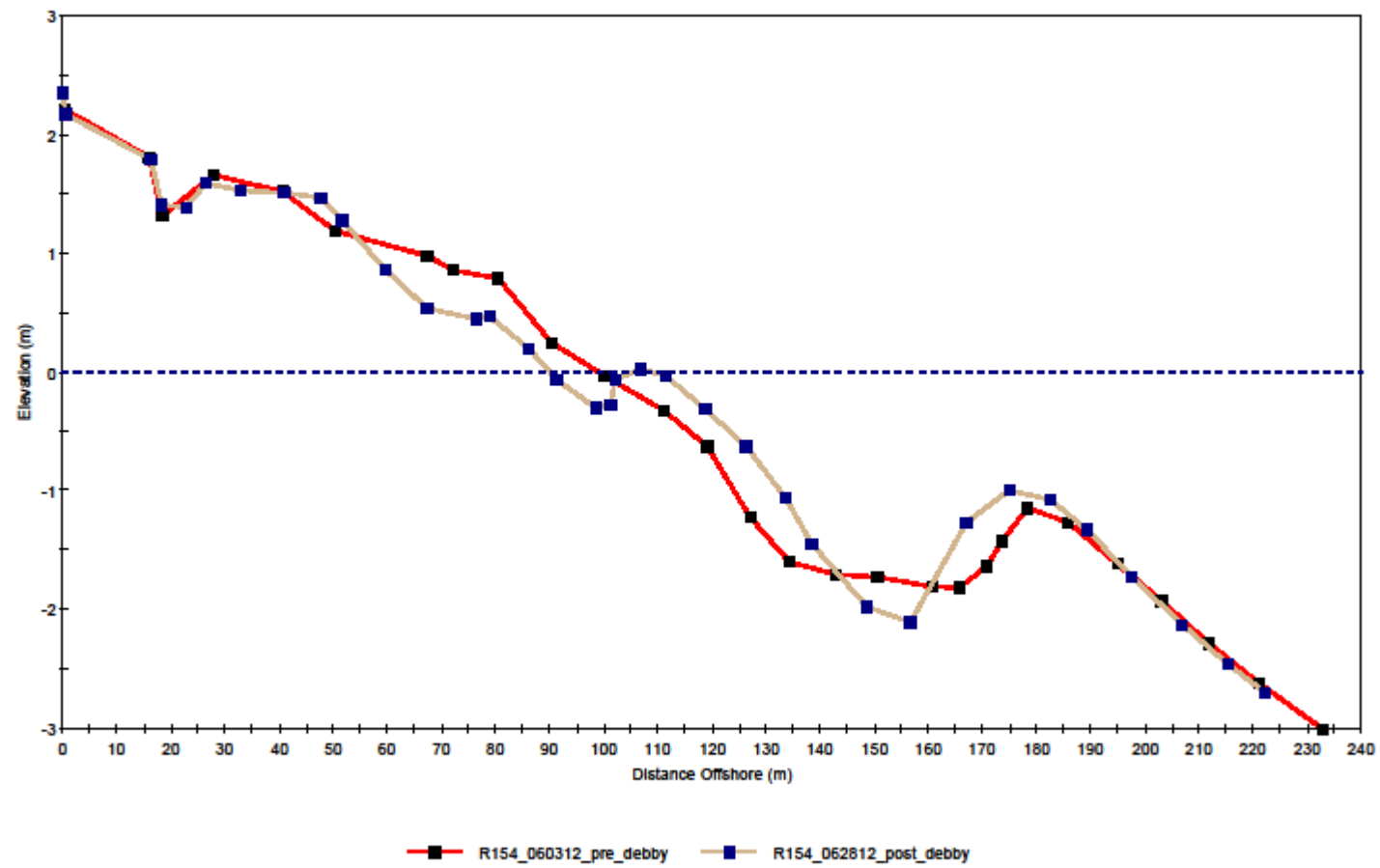
R152



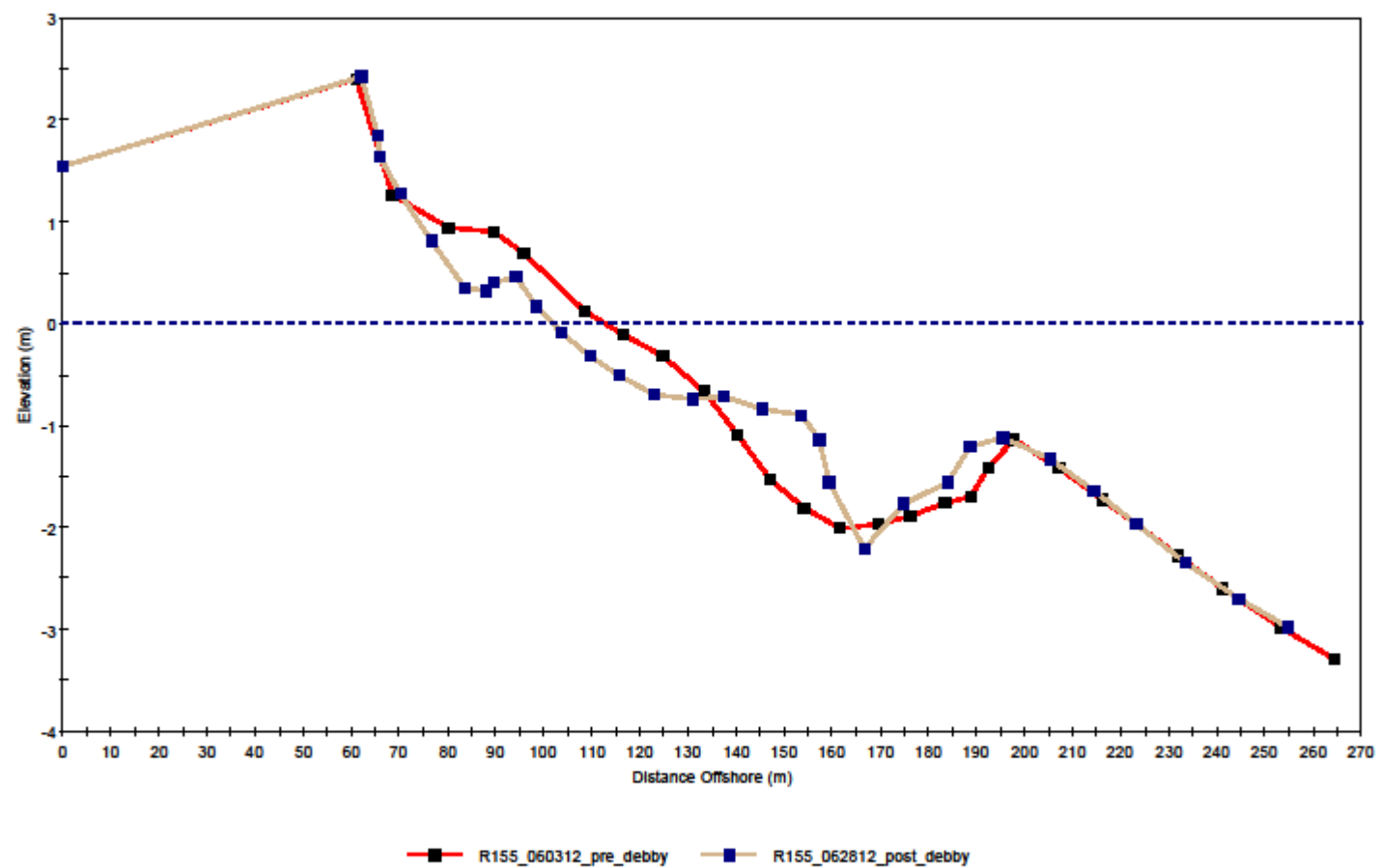
R153



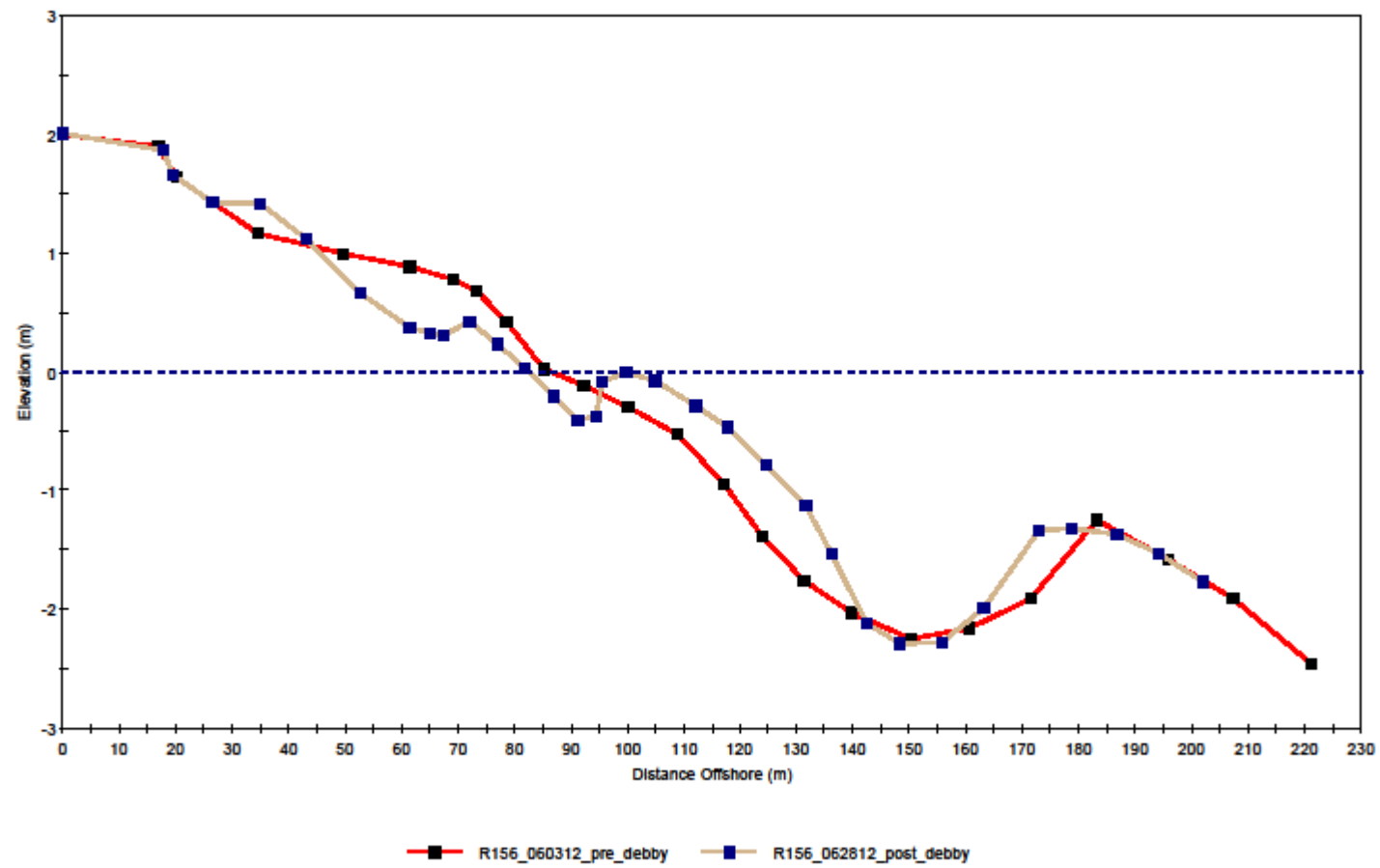
R154



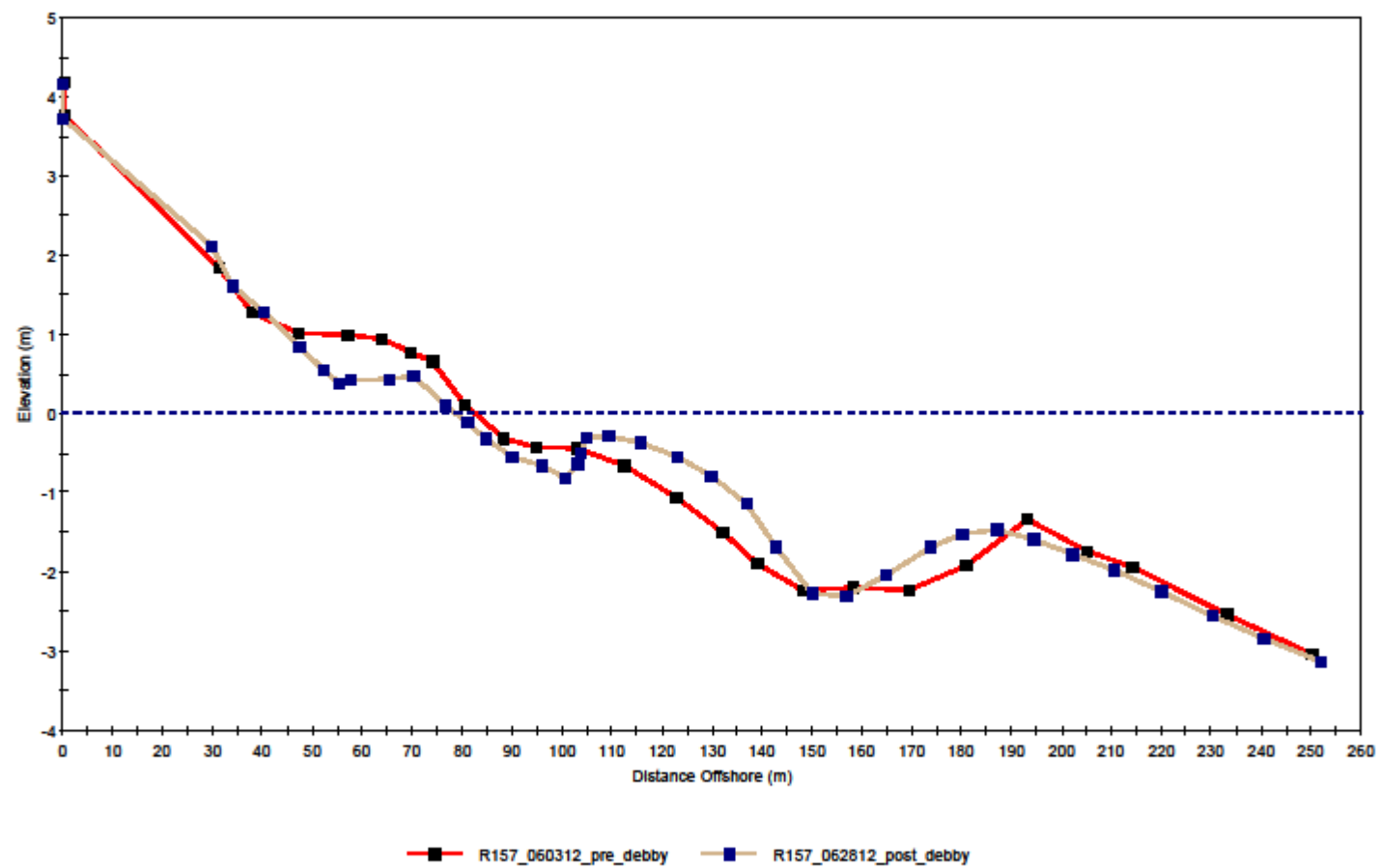
R155



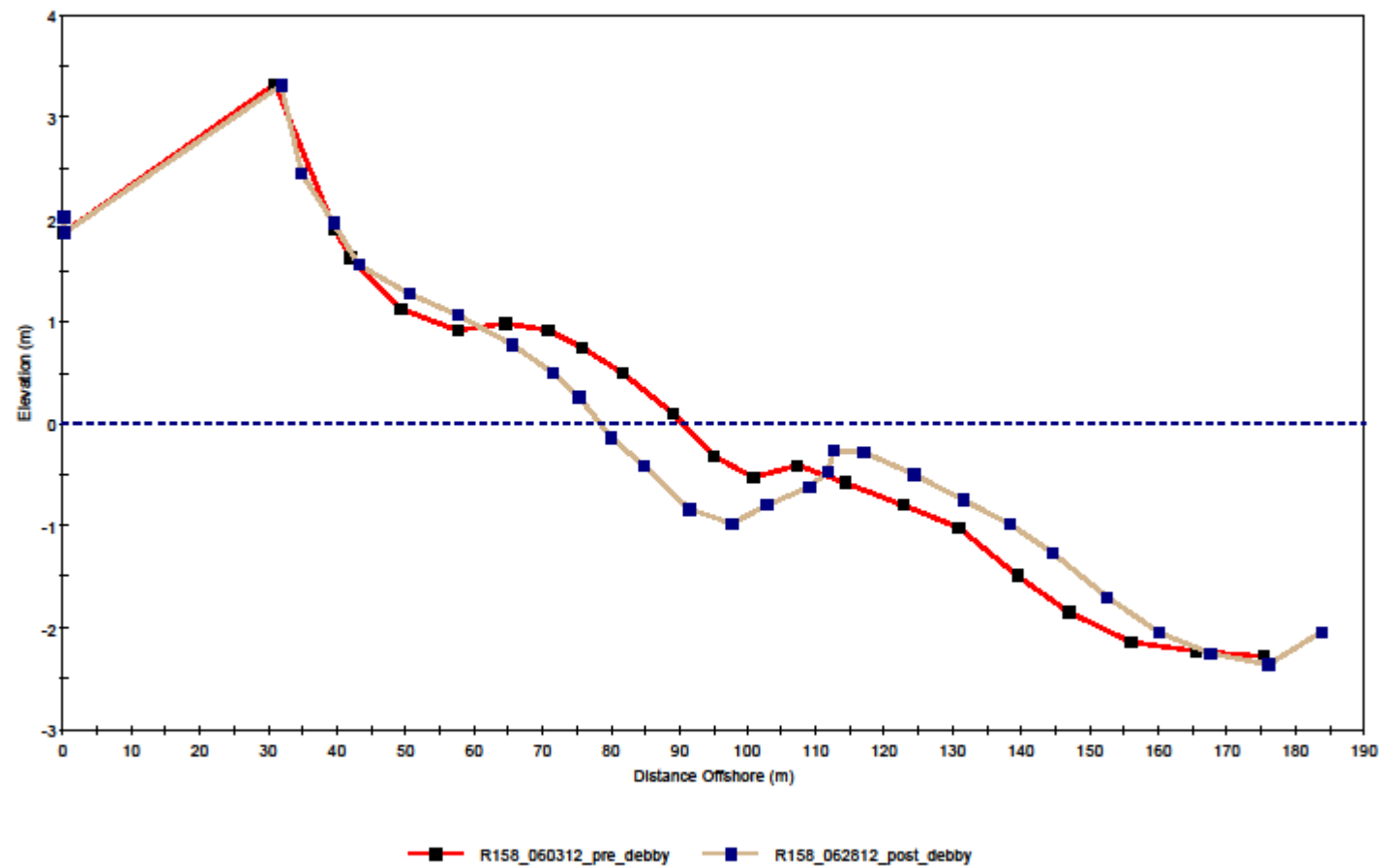
R156



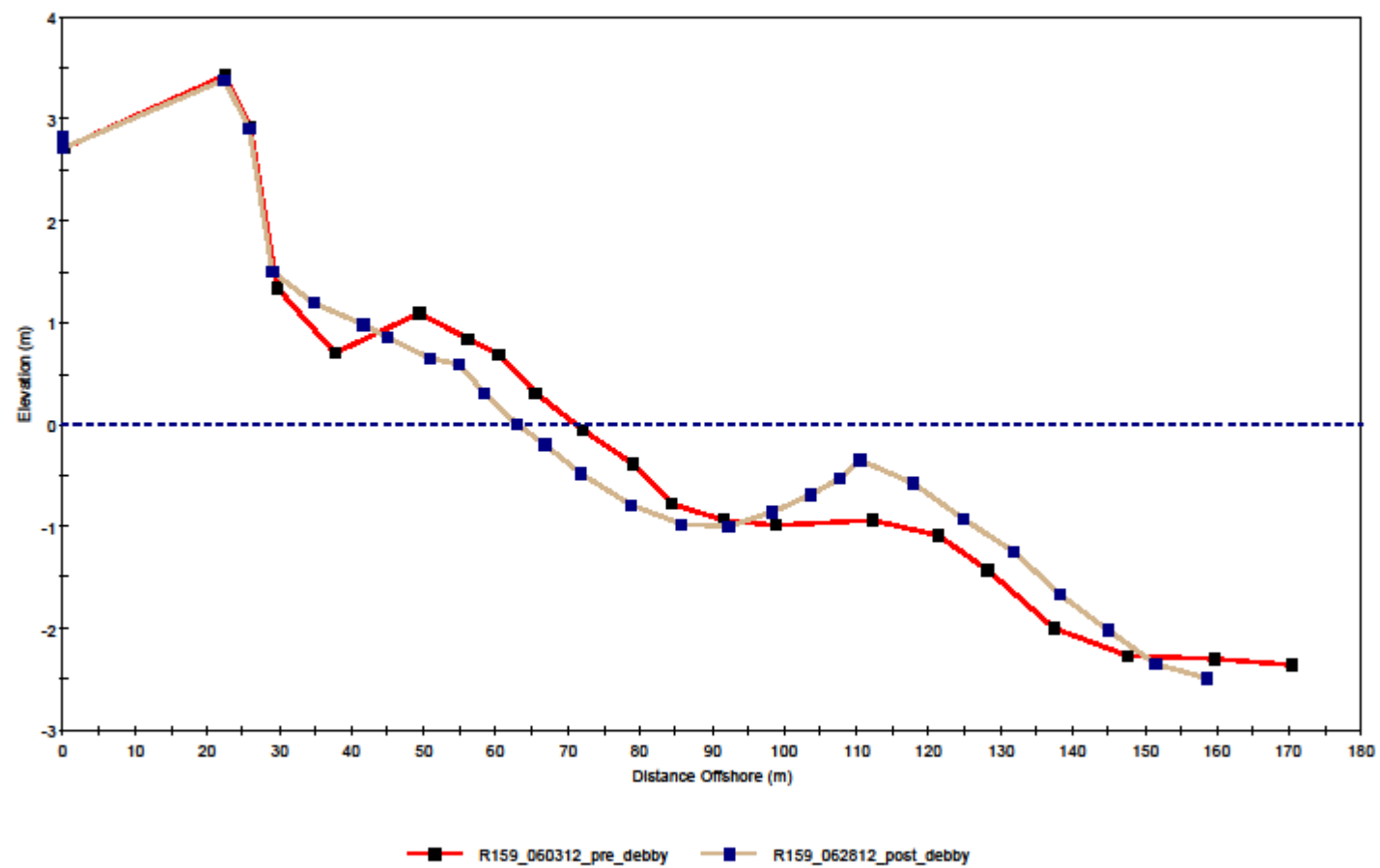
R157



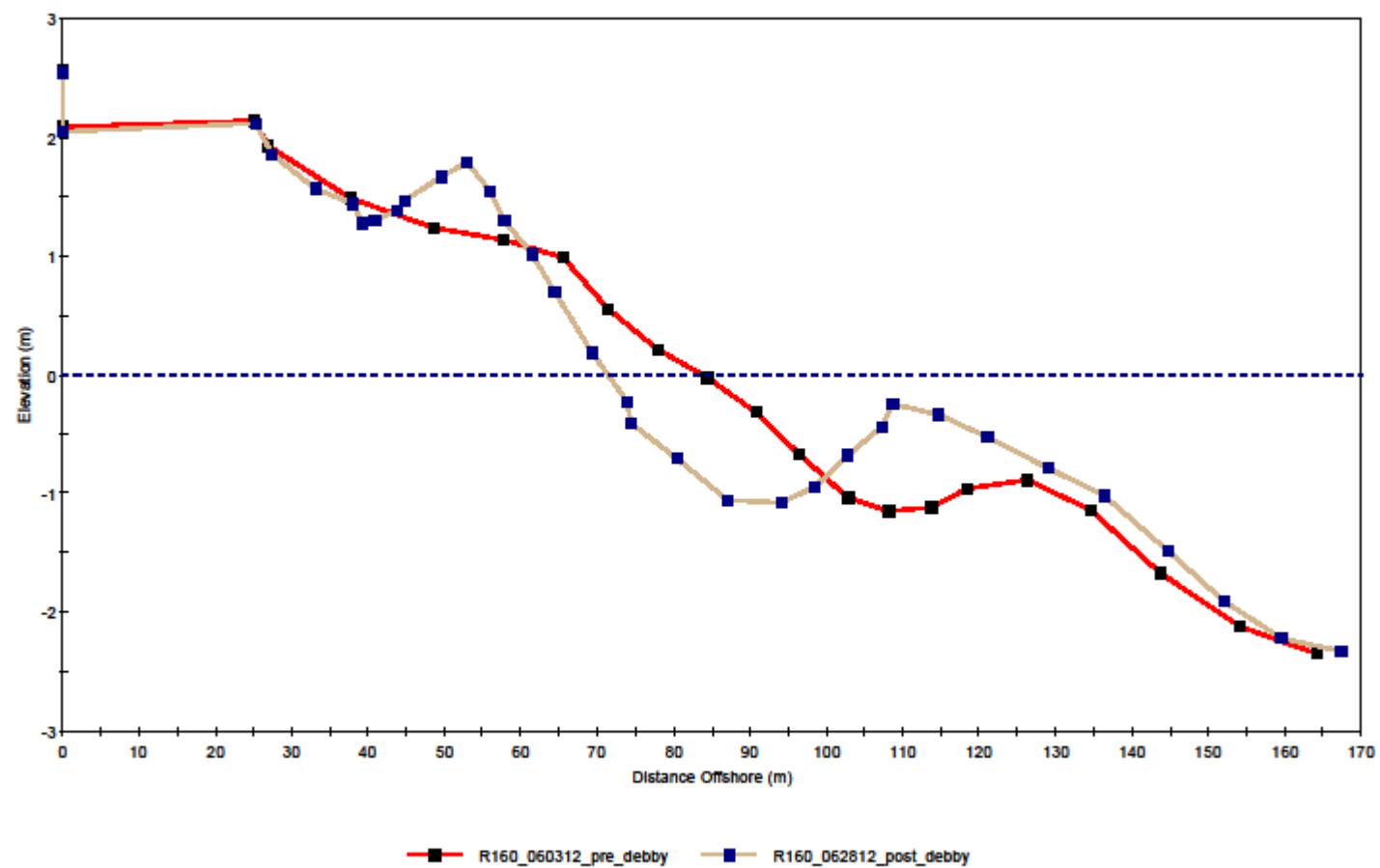
R158



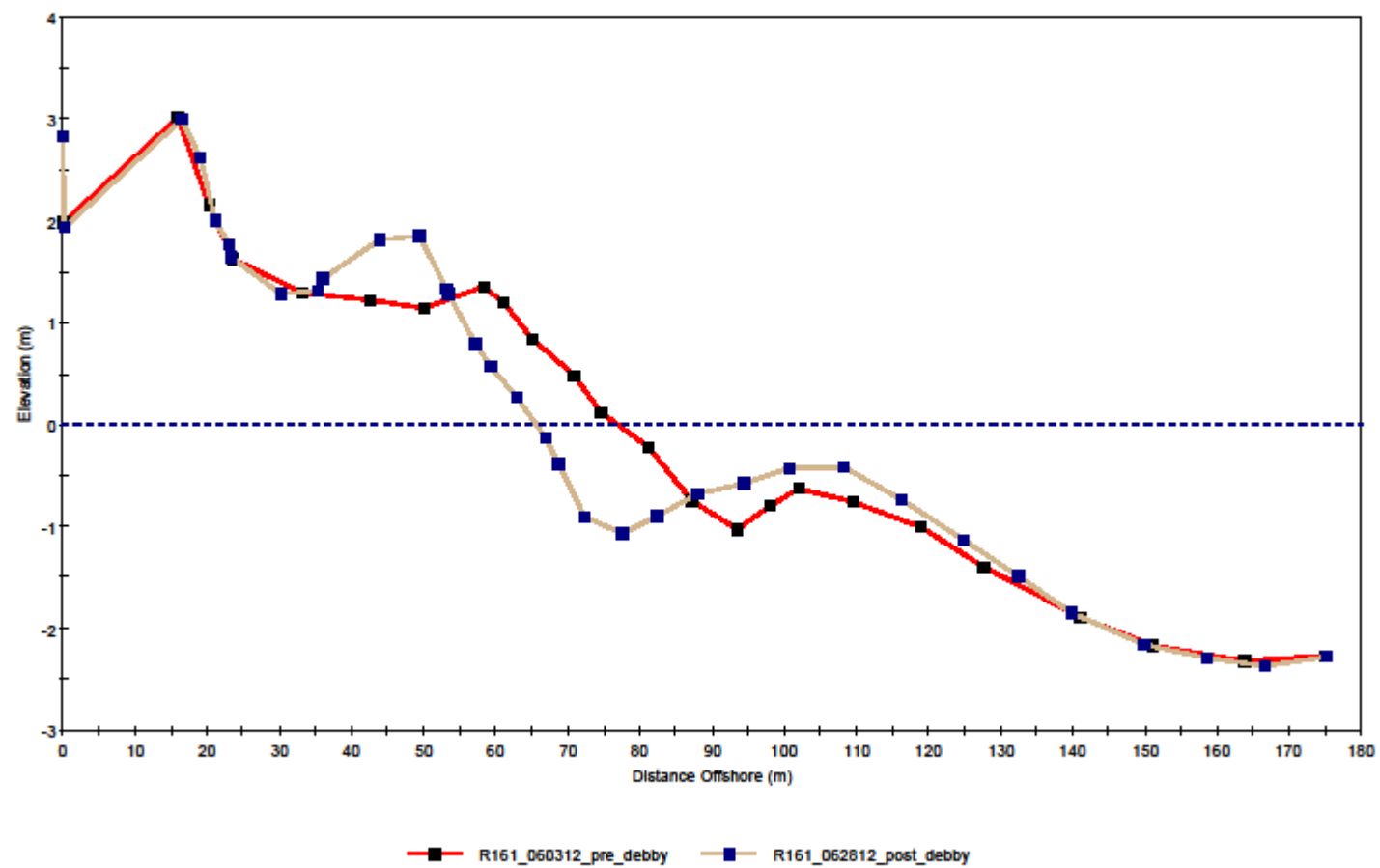
R159



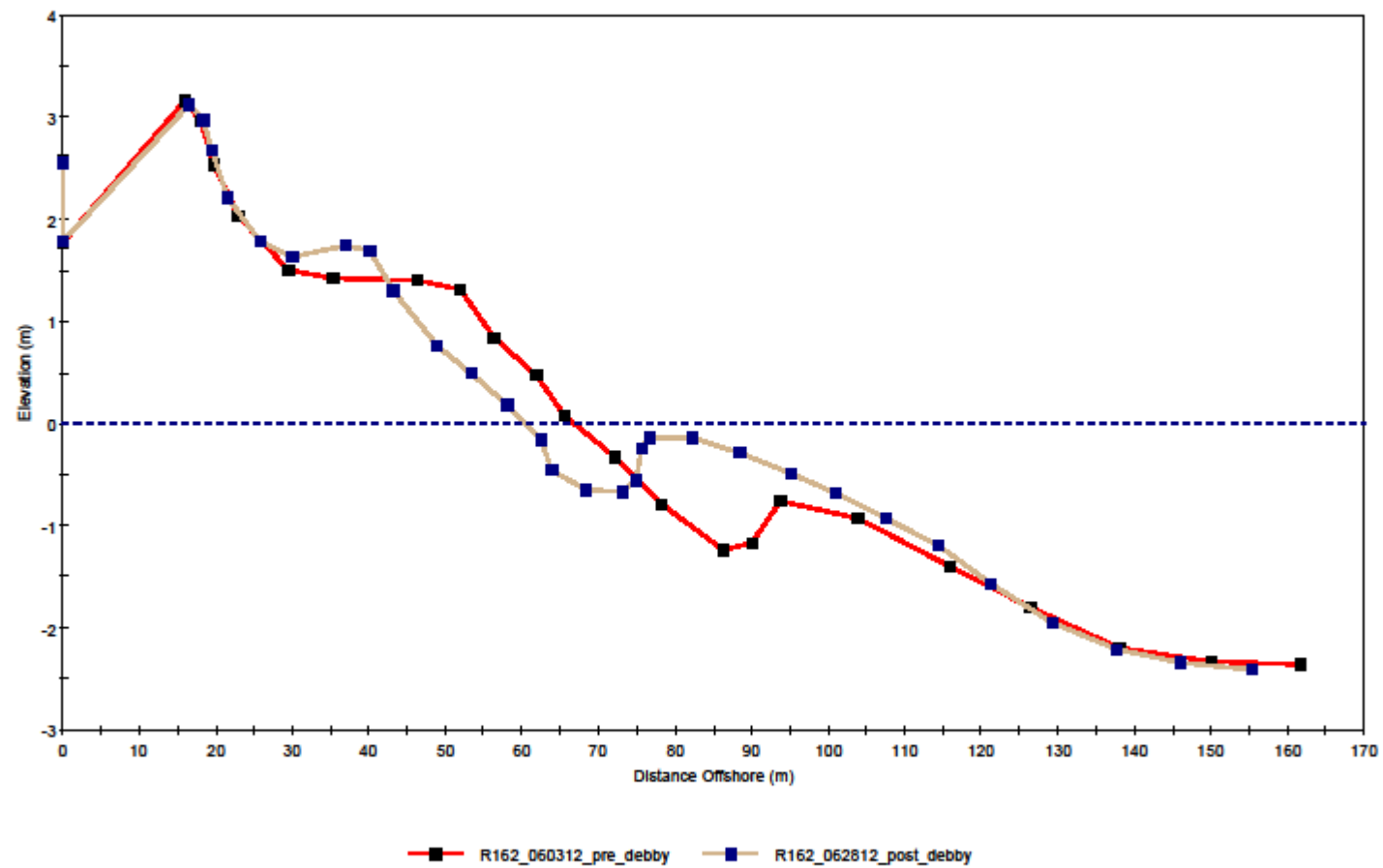
R160



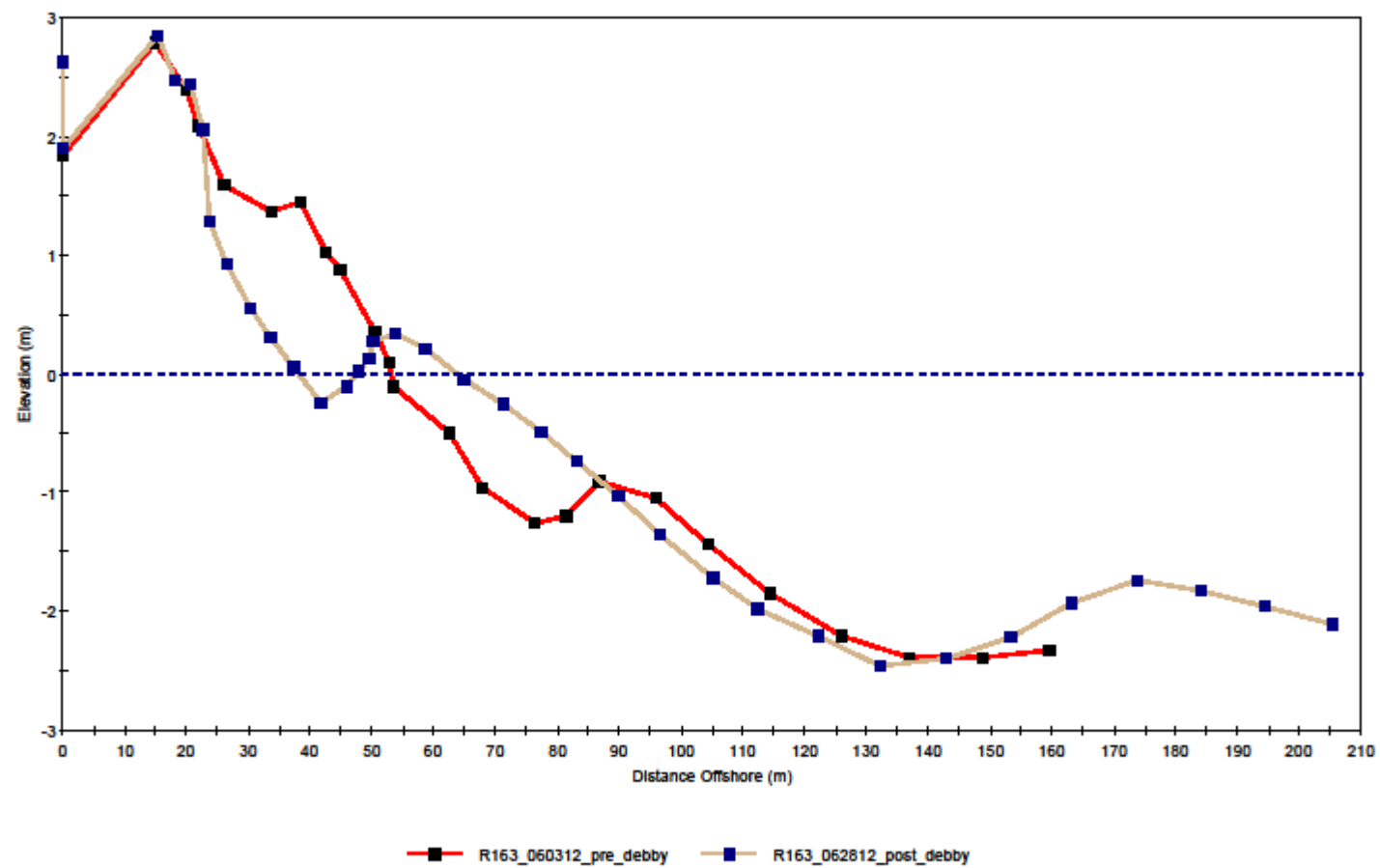
R161



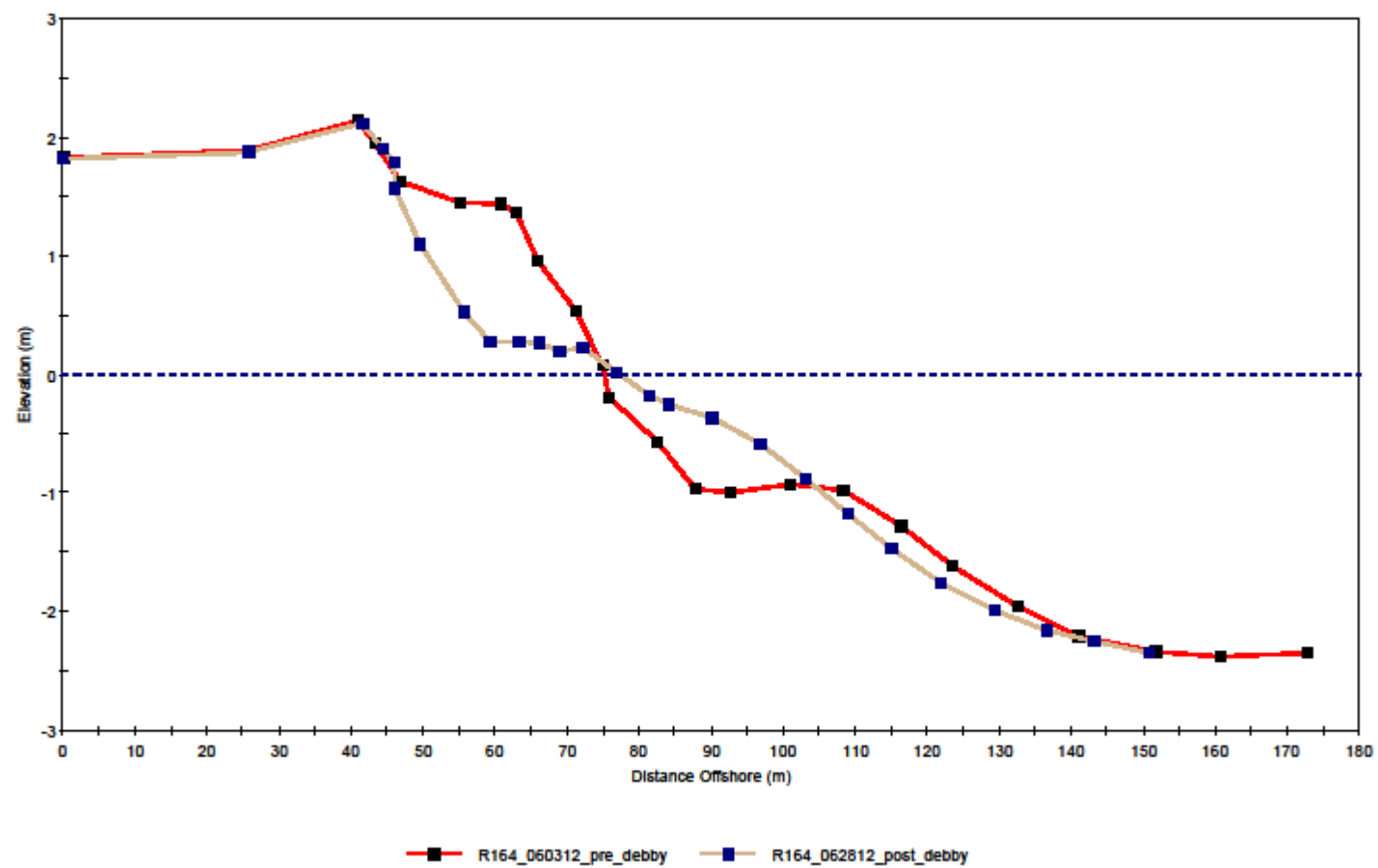
R162



R163



R164



R165

