Design Brief

Hamilton Harbour Waterfront Trail Shoreline Protection

City of Hamilton

Final

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Executive Summary

In the spring of 2017, Lake Ontario water levels reached historical levels, exceeding the 100-year design water level of 76.0 m (IGLD) set in 2011. The City of Hamilton also experienced two significant rainfall events accompanied by strong winds from the east. The combination led to flooding and significant erosion or damage to multiple assets throughout the City.

SNC-Lavalin Inc. was contracted by City of Hamilton to investigate and propose conceptual solutions for the rehabilitation of the Hamilton Harbour Waterfront Trail shoreline protection and trail reconstruction. The Hamilton Harbour Waterfront Trail (HHWT) is a 3.4-kilometre-long multi-use asphalt trail that makes its way along the west shore of Hamilton Harbour from Bayfront Park through the Desjardins Canal and continues to Princess Point.

SNC-Lavalin coastal engineering team in collaboration with the civil/structural engineering team are providing two budgetary design alternatives for the trail considering the adaptation to extreme events. In addition, two shoreline protection alternatives are provided considering non-conventional design approaches.

The summary of the shoreline design options is presented below:

- Option 1 considered a conventional revetment with a berm to reduce wave energy and crest elevation.
- Option 2 consists of a submerged habitat reef (breakwater) to break the waves and provide protection to the trail shoreline. The rock size and trail elevation are reduced when compared to Option 1.
- Option 3 considered stepped revetment which can reduce the wave overtopping by introducing the slope roughness.
- Option 4 is an alternative to Option 2 shoreline protection. Using the protection from the submerged reef, this option includes the creation of a perched beach with gravel or sand material. Considering that the reef is not continuous, the perched beach would be created for selected sections of the shoreline.

The design water level for these conceptual solutions considered measured data from three stations and the recent levels from spring 2017 and 2019. A numerical wave model (CMS-Wave) was conducted to understand the extreme wave conditions at the site and estimate the design wave for the shoreline protection.

The proposed trail alignment will be kept in the same location as the existing for this study. Trail construction cost including earthworks are estimated for the two main design options.

The proposed main design options were reviewed, and complimentary structural designs were developed and evaluated to protect the trail as well as keep it within the project limits. With these design options, retaining walls will be required along the west edge of the trail. The associated costs for the construction of the retaining walls are estimated for each option and included in the overall costs of the trail protection options.

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1. Introduction

1.1 Overview

The Lake Ontario water level rise and the co-incident wind/wave storms are the main cause of the observed shoreline damage and erosion of the City of Hamilton shoreline assets. As part of the comprehensive study of the shoreline protection, SNC-Lavalin Inc. (SNCL) was retained by City of Hamilton to provide engineering conceptual design for shoreline protection solutions to the Hamilton Harbour Waterfront Trail (HHWT) including raising the trail elevation to consider the current extreme water levels at Lake Ontario. The design was developed by SNCL’s coastal engineering team in collaboration with the civil and structural team.

The HHWT is a 3.4-kilometre-long multi-use asphalt trail that makes its way along the west shore of Hamilton Harbour from Bayfront Park through the Desjardins Canal and continues to Princess Point. The trail connects to the Trans Canada Trail, the Lake Ontario Waterfront Trail in Burlington, and the Desjardins Canal bordering Cootes Paradise.

The 2-kilometer section of trail spanning from Bayfront Park to the floating bridge located within the Desjardins Canal is the focus of this design.

Figure 1 shows the trail location.

Figure 1: View of Hamilton Harbour Waterfront Trail

1.2 Metocean Conditions

Metocean (meteorological and oceanographic) conditions at the site were assessed in Ref.[2]. This reference is the basis for the definition of existing and future metocean conditions at the site.

1.2.1 Winds

Wind analysis has been performed by SNC-Lavalin during the Shoreline Inventory and Assessment of the City of Hamilton owned assets (Ref.[2]). Among the three measurement stations considered in the area (Hamilton A, Burlington Piers and C45139 (West Lake Ontario), Hamilton A station was selected as the most representative station for extreme wind analysis since the period of measurement is longer than the other stations, which increases the reliability of the results. Figure 2 shows the annual wind rose from Hamilton A station for the past 48 years (1970-2017). The maximum wind speed observed during the past 48 years (1970-2018) was approximately 31 m/s and calm conditions occurred in approximately 3% of the records.

Table 1: Bivariate histogram wind speed and direction Hamilton A Station (1970-2018)

	UDir (from deg T)																
U (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
>20.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
15.0 - 20.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0%
10.0 - 15.0	0.0%	0.1%	0.4%	0.5%	0.0%	0.0%	0.0%	0.0%	0.1%	0.3%	0.7%	1.0%	0.7%	0.2%	0.1%	0.0%	4%
5.0 - 10.0	1.0%	1.4%	3.3%	3.3%	0.7%	0.1%	0.1%	0.2%	1.4%	3.3%	4.5%	5.4%	5.1%	2.6%	1.8%	0.9%	35%
0.0 - 5.0	3.0%	3.0%	4.8%	4.4%	3.0%	1.0%	0.9%	1.4%	4.0%	4.6%	5.6%	6.1%	7.4%	3.4%	2.6%	2.0%	57%
< 0.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%
Calm																	3%
Total	4.0%	4.6%	8.5%	8.3%	3.7%	1.1%	1.0%	1.6%	5.4%	8.1%	10.9%	12.7%	13.2%	6.2%	4.5%	3.0%	100%

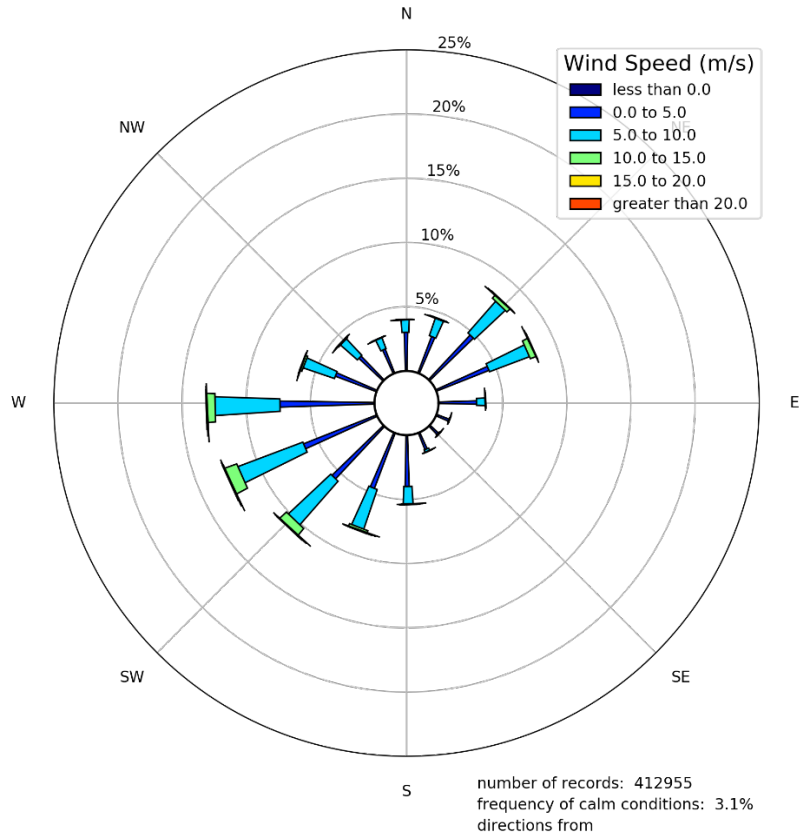


Figure 2: Wind Rose from Hamilton A Station (1970-2018) (Ref [2])

Wind speeds with Annual Exceedance Probability (AEP) of 1:10, 1:25, 1:50, and 1:100 were calculated for directions NE, E and SE. Table 2 shows the extreme wind analysis for the wind directions of interest. More detailed information about these wind stations data can be found in Ref.[2].

Table 2: Extreme wind speed by direction for Hamilton A Station (Gumbel)

AEP	NE	E	SE
1:10	20.2 (18.4 to 21.9)	16.7 (15.5 to 17.9)	1.8 (9.8 to 11.9)
1:25	22.4 (20.0 to 24.7)	18.2 (16.6 to 19.7)	12.2 (10.8 to 13.5)
1:50	24.0 (21.2 to 26.8)	19.2 (17.4 to 21.1)	13.1 (11.5 to 14.8)
1:100	25.6 (22.3 to 28.8)	20.3 (18.1 to 22.5)	14.1 (12.2 to 16.1)

A wind wave numerical model was conducted to determine the deep water design wave conditions at the HHWT. The extreme wind events with AEP of 1/100 from NE (26 m/s) and E (20 m/s) were considered as model inputs.

1.2.2 Water Levels

The water levels were obtained from three stations in close proximity of the area of interest. Figure 3 shows the location of the stations.

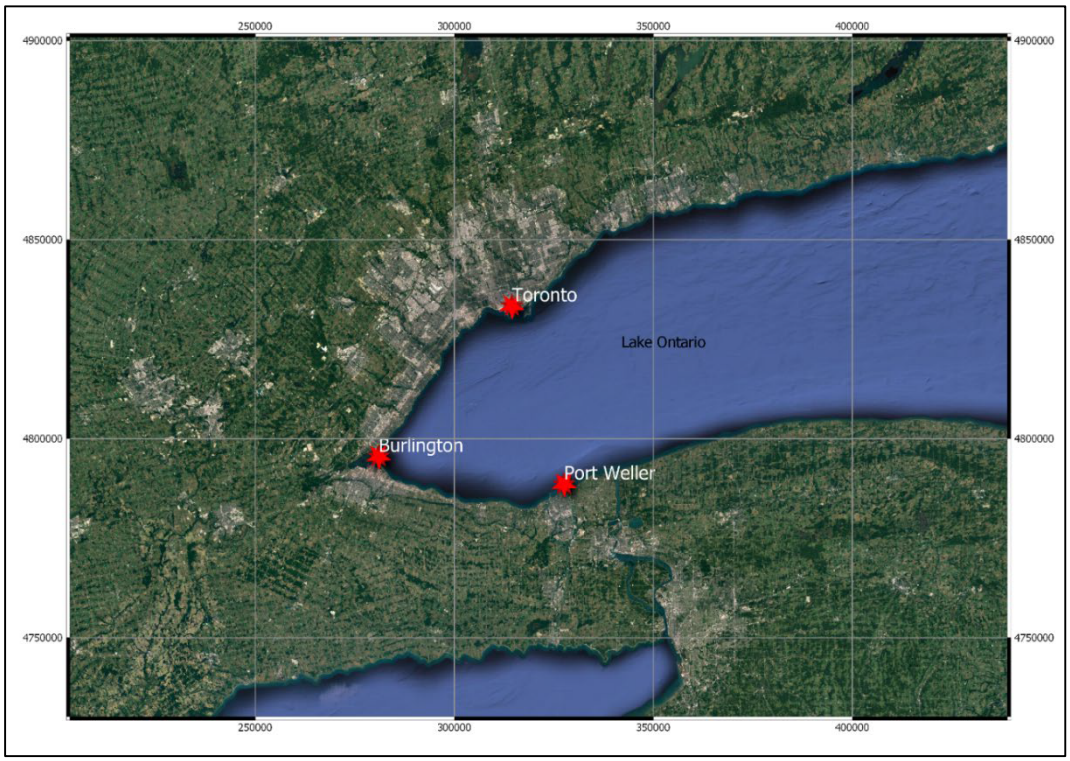


Figure 3: Location of the Water Level Stations

The extreme value analysis was conducted for the three stations. The Burlington station is the closest to the site of interest; however, only 11 years historical record is available in this station. Port Weller and Toronto stations have historical water level data of 58 years (1962-2019), thereby the extreme value analysis is more reliable in these stations. Figure 4 indicates the annual maximum water level over the last 11 years.

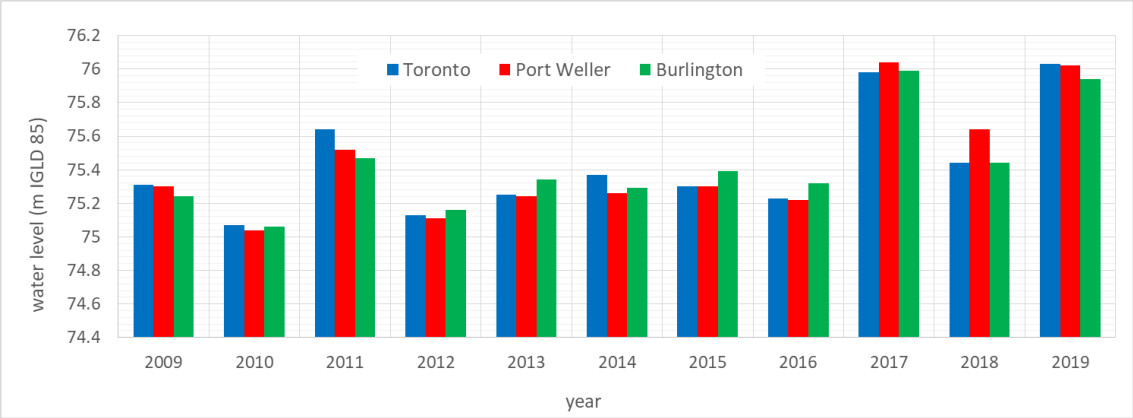


Figure 4: Historical Maximum Measured Water Level

The maximum water level of 76.04 m was registered at Port Weller station in 2017.The annual comparison of water level in Figure 4 indicates that the past few years' high-water level can be attributed to recent changes to the Great Lakes water regimes driven by climate change effects.

Table 3: Design Water Levels

Annual Exceedance Probability	Extreme Water Level Analysis (m IGLD)		
	Port Weller	Toronto	Burlington
1:10	75.7 (75.5 to 75.9)	75.6 (75.5 to 75.8)	75.8 (75.4 to 76.2)
1:25	75.9 (75.7 to 76.1)	75.8 (75.6 to 76.0)	76.1 (75.5 to 76.6)
1:50	76.1 (75.8 to 76.3)	75.9 (75.7 to 76.2)	76.2 (75.5 to 76.9)*
1:100	76.3 (76.0 to 76.6)	76.1 (75.8 to 76.3)	76.4 (75.6 to 77.2)*

*shorter time series

The 100-year flood level at 76.0 m at the Lake Ontario Shoreline is reflected in the 2011 guidelines from the Hamilton Conservation Authority (Ref.[1]).

The extreme value analysis over the records at three water level stations close at Lake Ontario (Burlington, Toronto and Port Weller) indicates that the 1:100 AEP water level varies from 74.1 to 76.4 m IGLD7 (equivalent to 2.2 m CD), see Table 3 for details. The design water level is set to 76.4 m IGLD at this conceptual level stage.

1.2.3 Currents

The wind driven currents are not expected to govern the nearshore processes at the area of interest.

1.2.4 Waves

A numerical wave model (CMS-Wave) was conducted to understand the extreme wave conditions at the site and estimate the design wave for shoreline protection.

The extreme events used for model input consider the AEP of 1:100 from NE (26 m/s) and E (20 m/s). Section 2 describes the wave model inputs and outputs.

1.2.5 Trail

The existing trail is asphalt constructed with an average width of 6 m. There are various lookout points along the trail with seating areas. For the purposes of this study, a proposal trail width of 6m will be considered. Features such as lookout points will be reserved for the detailed design.

2. Numerical Wave Model

2.1 Inputs

2.1.1 Reference system

The horizontal and vertical reference datum used in this model is given in Table 4 unless indicated otherwise.

Table 4: Coordinate system used in the wave modelling

Parameter	Value
Horizontal datum	UTM Zone 17N (NAD 1983)
Vertical datum	Chart Datum

The vertical elevations for the wave model are referenced to the Chart Datum (CD). Chart Datum is equivalent to 74.2 m International Great Lakes Datum 1985 (IGLD).

2.1.2 Bathymetry

The bathymetry used for the generation and propagation of the waves is a compilation of nautical chart (CHS N.2077), topographic and bathymetric data provided by the City of Hamilton, and SNC-Lavalin bathymetric survey sections (conducted during the spring 2019).

The three sets of data overlapped in some areas. Those areas have been checked so that the bathymetry was smooth between the different sources. The vertical elevations are referenced to Chart Datum.

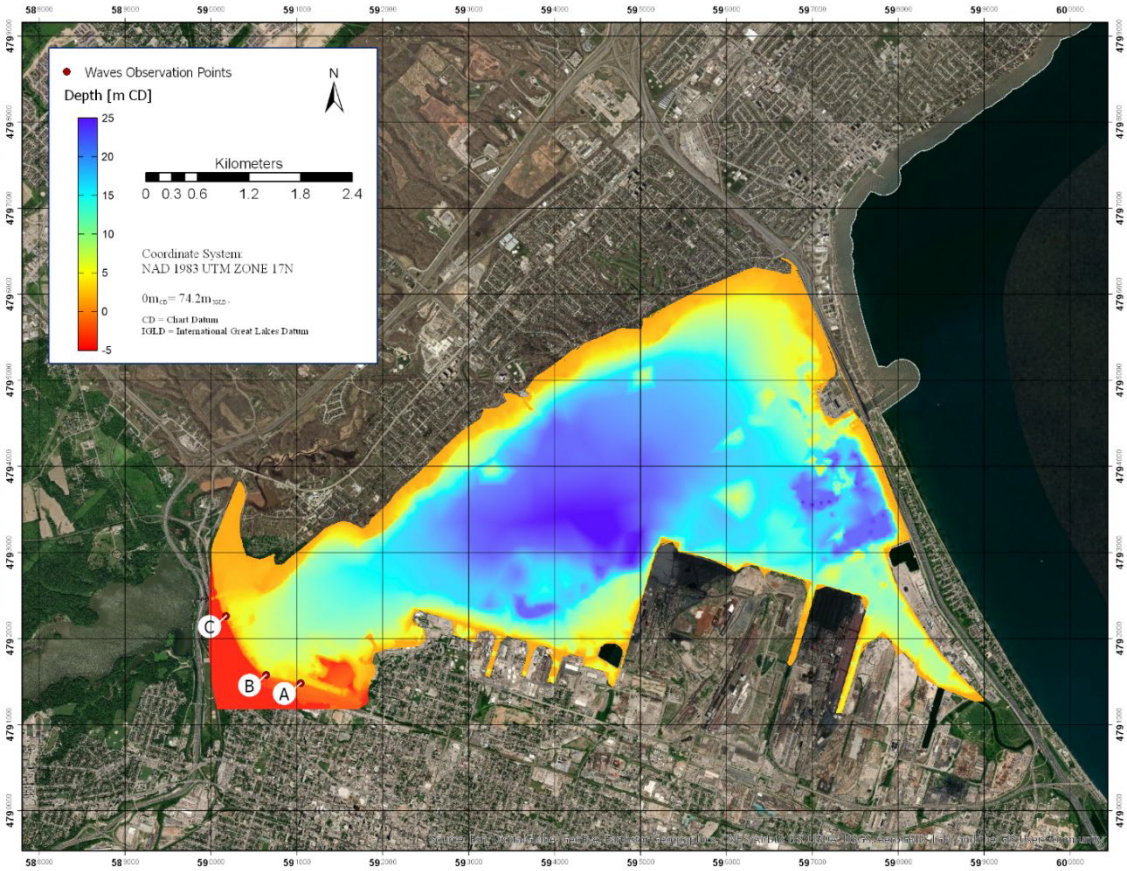


Figure 5: Model Bathymetry and Output Locations

Once the new scatter set of data was merged, cleaned and checked, the bathymetry was interpolated over a uniform grid. The grid cell size of 5.0 m was selected to represent properly the existing artificial islands close to the trail.

2.2 Runs

Considering that the HHWT shoreline is more exposed to directions NE and E, those were the directions used in the wave model. Table 5 shows the wind and water level conditions used in the model based on the extreme value analysis described in Section 1.2.2.

Table 5: Bathymetry, Wind and Water Level Conditions

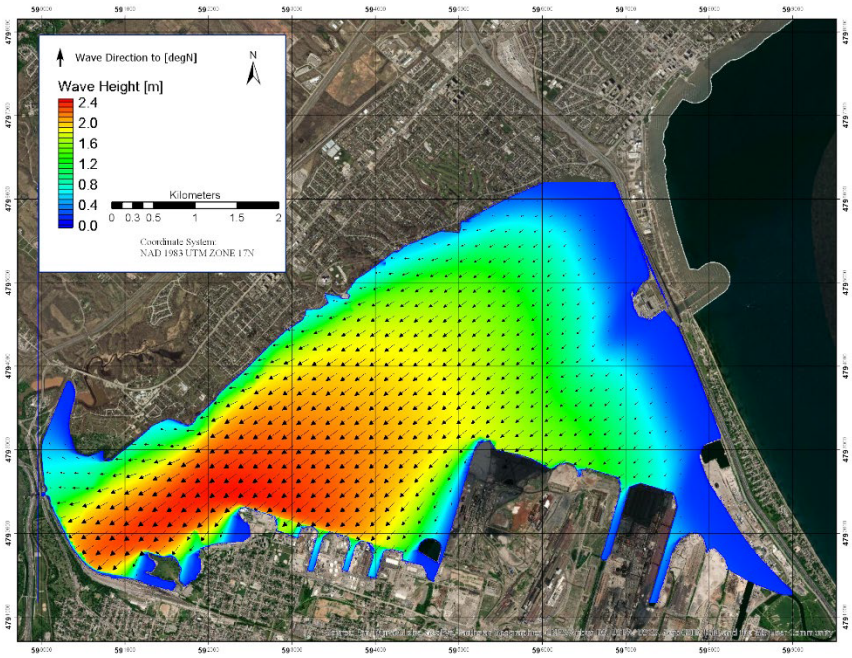
Run case	Water Level condition [m CD]	Wind Speed (m/s)	Wind Direction (deg N)	Bathymetry
1	2.2*	26	NE	Actual
2	2.2*	20	E	Actual

*2.2 m CD equivalent to 76.4 m IGLD

2.3 Wave Climate

The significant wave height and direction results for the two first cases are presented on Figure 6. For each case, the results were extracted at specific locations (Figure 5). Table 6 shows the significant waves height at the selected observations points. Northeast winds generate the highest waves for points A and B. The wave heights generated from easterly winds are slightly higher at Point C because of the larger fetch at the location.

(a)



(b)

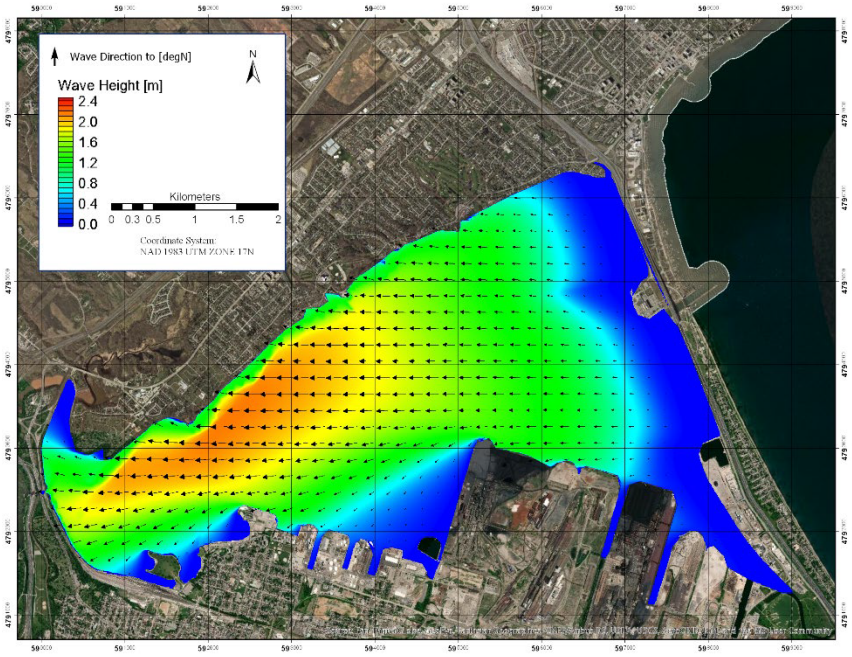


Figure 6: Wave fields for the Run NE(a) and Run E(b).

Table 6: Significant Wave at Observation Points for the NE and E Cases with the Actual Bathymetry

Wind Conditions	Observation points	Significative Wave Characteristics		
		Height	Peak Period	Direction to
		[m]	[s]	[Deg N]
NE 26 m/s	A	0.9	3.3	205
	B	2.0	4.0	225
	C	1.2	3.7	260
E 20 m/s	A	0.3	2.3	205
	B	0.8	3.2	230
	C	1.5	4.0	270

2.4 Model limitations

The wind scenarios are based on data from Hamilton Airport, which is about 15 km inland. The station was selected because the time series was long enough to run a proper statistical analysis, but the wind is slightly distorted compared to the wind acting over the lake.

Wind speed and direction are considered uniform over the grid so the waves can develop to the maximum of the energy the wind gives. As wind changes over time and space, this could overestimates the wave results.

Section 2.1.2 presents how the bathymetry data were merged to have the best resolution available, but greater resolution is limited to the surveyed sites in 2019. An overall coastal high-resolution bathymetry would allow a better wave refraction assessment.

Finally, CMS-Wave is a spectral phase-average model which was developed for coastal modeling, but strong wave reflection, breaking and diffraction near structure would need an equivalent to phase-resolved wave modelling to have a more detailed assessment.

3. Shoreline Protection

As described in Section 1.2.2, the water levels at Lake Ontario exceeded the current recommended 100-year design water level in 2017 and 2019. The current trail shoreline elevation is approximately 50% under the SNC-Lavalin updated design water level for the site. All suggested solutions to protect the trail shoreline include raising the elevation of the pathway to provide protection during extreme water level events.

Four hybrid shoreline protection solutions that could reduce costs and create benefits to public access are proposed in this scope of work. Sections 4 and 5 describe the civil and structure works necessary to complete these shoreline protections onshore. The concepts were developed based on the following assumptions.

- The design options replace the existing shoreline protection with a new solution rock armour design that meets the required crest height, material size/type, shoreline protection slope on the front side, and toe design based on design guidelines (Ref.[3]). However, free board[1] allowance was not included in the crest elevation design due to site limitations.

- The shoreline cross sections were designed for the most exposed location. Detailed sections along the shoreline considering the wave height change (reduction) should be developed in the next design stage.

- The shoreline protection structure will be designed to prevent the waterfront trail from inundation and address the erosion of the pathway. The overtopping discharge limit was selected based on the hazard type, application of the structure, and level of damage (Ref. [3 and Ref.[4]). The design allows a minimum overtopping volume during extreme storm events, and it is expected that the structure will receive no damage.

- The design criteria consisted of preliminary acceptable levels of overtopping for the extreme wind and water level events with an Annual Exceedance Probability of 1:100.

- The crest height (and recommended trail elevation) is based on the extreme conditions above, limited overtopping to keep the trail opened to public, and avoid damage to the shoreline. Freeboard[1] allowance was not included in the design. Overtopping volume was considered as a minimum to allow safe use of the trail.

- Approximately 50% of the trail shoreline is under still design water level[2] of 76.4 m (without considering wave effects). It means that the trail needs to be raised to avoid flooding during the extreme water level event (AEP = 1:100). Any shoreline protection that keeps the current trail elevation will likely be flooded during extreme water level event.

3.1 Option 1

Option 1 considered a conventional revetment with a berm to reduce wave energy and crest elevation.

The wave overtopping during extreme events was reduced to an acceptable level by raising the crest and trail elevation. This acceptable level is not expected to cause damage to the trail or be a hazard to the public. Drainage on the lee side (sheltered side) of the shoreline protection structure is considered to prevent the low overtopping from eroding to the pathway or accumulation of water after extreme events.

The crest is elevated to protect the shoreline from extreme water level and wave impact. Considerations to the elevation must be done during detailed design, when the City will be able to define risk and limit of overtopping volume. The slope 1V: 2H was adopted to consider ground improvement and geotechnical stability in the shoreline protection design. A berm is included to allow wave energy dissipation before it reaches the structure crest. This approach helped to reduce the structure crest elevation. Two layers of

[1] Freeboard: A vertical distance added to the Designated Flood Level. It is used to establish the Flood Construction Level and tends to compensate for the many unknown factors that could contribute to future changes to storm surge, wave run-up, and the effects of climate change.

[2] Still Design Water Level: Design water level before adding wave effects

rock armour and filter are used for this design. An extra layer of boulders is placed at the crest to increase protection without the need of additional raising of the trail, it will also improve the trail landscape.

This option also included one meter of transition from crest armour to 0.5 m of vegetation at the backshore to protect the trail against erosion caused by potential overtopping (splashes). These dimensions must be confirmed at detailed design stage according to design criteria and the City’s purposes. Figure 7 shows the Option 1 proposed solution.

The proposed trail elevation is approximately 1 m to 2 m higher than the existing trail. This results in significant impact to property on the inland side and also requires a large amount of imported material for the grade raise.

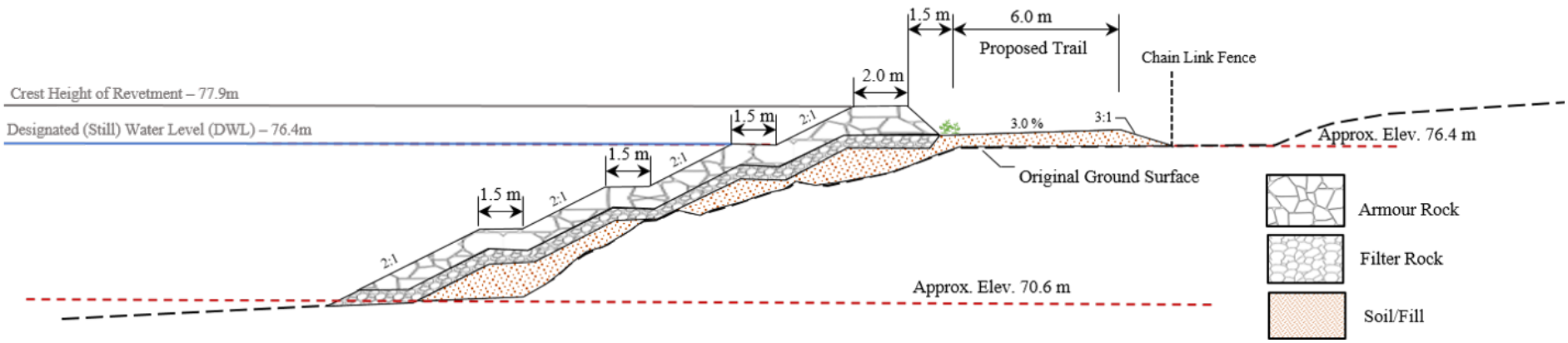


Figure 7: Option 1 Solution

3.2 Option 2

A solution with minimum crest and trail elevation is proposed in Option 2. A submerged habitat reef is considered in this solution to break the waves before reaching the shoreline. The shoreline protection is less robust than Option 1 since the wave energy is mostly dissipated in the reef.

The design water level, without wave effects is set to 76.4 m IGLD, so the trail elevation was raised to 77.0 m IGLD to avoid flooding. Armour rock size is also reduced (to a filter size rock) for this Option. Toe protection is considered at this stage and its dimensions can be optimized during detailed design.

Similar to option 1, drainage needs to be designed on the lee side of the shoreline protection crest to allow low overtopping volumes to drain before reaching the pathway.

The submerged reef concept is not continuous along the trail to avoid still water and the conditions to promote the bloom of blue-green algae. The length and extend of the reef must be detailed at the next design stage considering the wave impacts and the lake water quality.

The majority of the proposed trail at this elevation is above the existing trail by a maximum grade raise of 1 m and therefore poses less impact compared to Option 1. There are some sections where the proposed grading encroaches past the existing chain link fence and therefore require retaining walls as a mitigation measure.

Some cut sections were also observed with this Option 2 where the proposed trail is lower than the existing trail elevation. This issue can be mitigated by raising the profile to match existing grade or propose a short retaining wall which is further described in Section 6 of this report

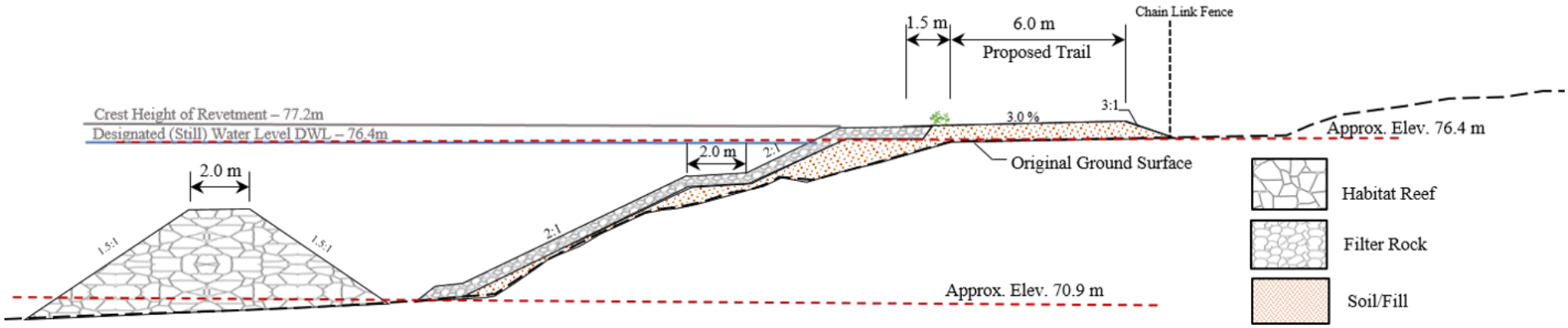


Figure 8: Option 2 Solution

3.3 Option 3

Option 3 considered a stepped revetment to reduce the wave overtopping by increasing the slope roughness.

Literature references indicated that stepped revetment can reduce the volumes of breaking water up to 60% comparing to the smooth slope ones (Ref.[7]). Stepped revetments not only provide coastal protection but also reduce the crest elevation, material size and provides secondary application such as tourism and recreation.

It is recommended for the HHWT that the stepped revetment is composed by boulders instead of concrete to increase the permeability and drainage of potential overtopping volume during storm events.

It provides similar protection to the other options, but the increased number of steps provides recreation and potential cost reduction.

Figure 9 shows a preliminary sketch of the stepped revetment considering slopes 1V: 2H, steps height and width of 1.5 m and 2.0 m, respectively. These preliminary dimensions are suggested based on references for different conditions and it must be confirmed in the next design phase.[3]

[3] A refinement of Option 3 is presented in Appendix D as requested by the City of Hamilton.

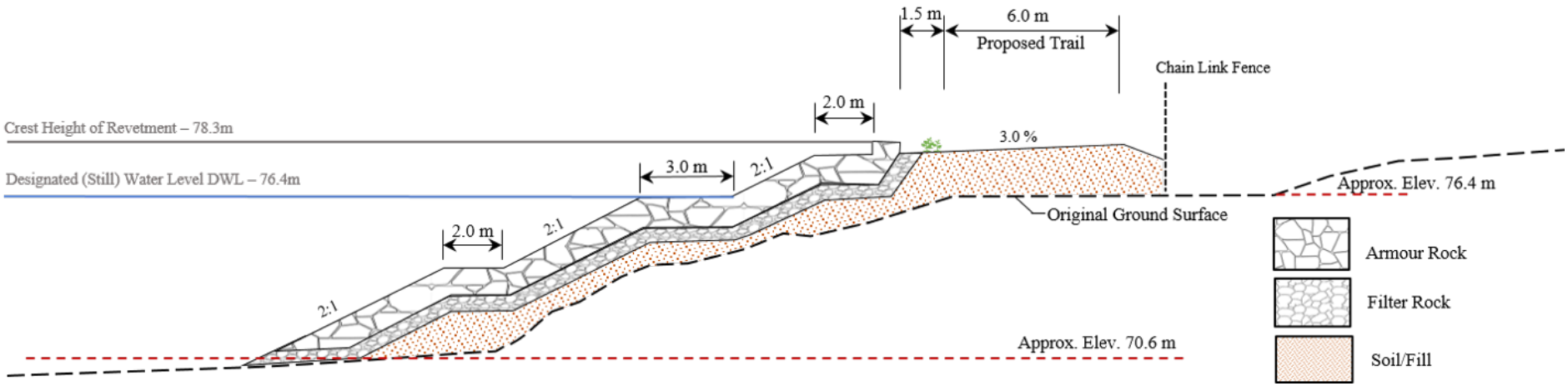


Figure 9: Option 3 Typical Cross-Section Stepped Revetment

3.4 Option 4

Option 4 is an alternative to Option 2 shoreline protection. Using the protection from the submerged habitat reef, this option includes the creation of a perched beach with gravel or sand material.

Considering that the reef cannot be continuous along the shoreline to avoid reduction of water circulation, the perched beach would be created for selected sections of the shoreline. Other sections would be similar to the one presented in Option 1 or Option 3. Figure 10 shows a sketch of the concept, where general fill is added to the lake to create the beach mild designed slope. Figure 11 shows the plan view of the proposed solution including perched beaches and rock armour.

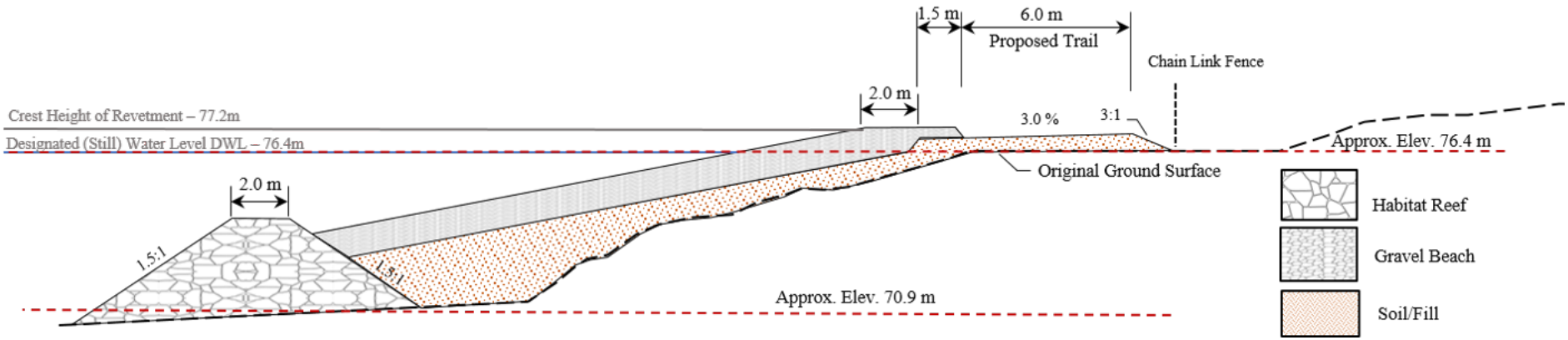


Figure 10: Option 4 Solution

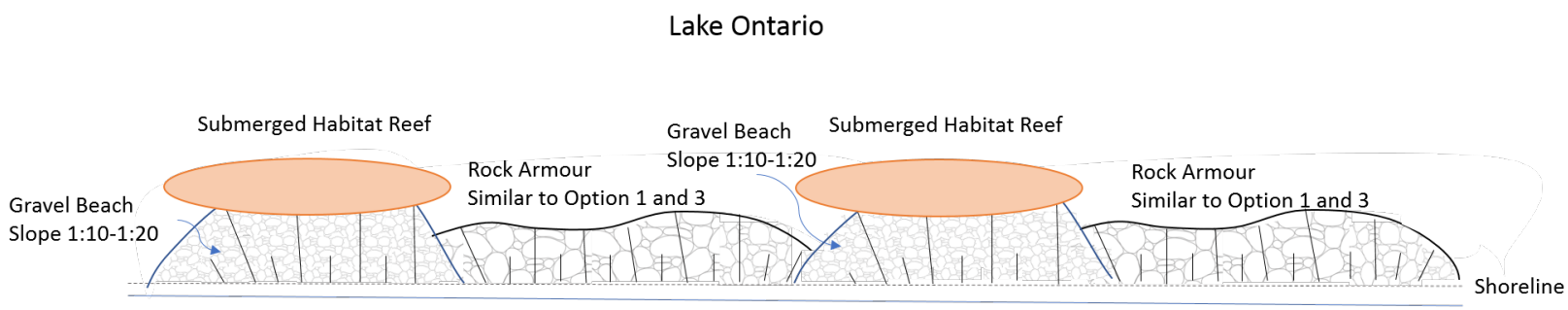


Figure 11: Plan View of Option 4 Solution

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4. Civil

With the preferred elevations of the proposed trail provided by the Coastal Engineering team, the profile of the centreline of the trail was developed. The proposed horizontal alignment of the trail was established using the alignment of the existing trail. Based on the typical sections presented in Section 3, preliminary cross sections at 20 m intervals were developed for Options 1 and 2. Refer to Appendix B for plan and profile drawings, and cross sections. Options 3 and 4 are considered minor deviations of Option 2, therefore were not analyzed for the entire corridor.

A typical grading slope of 3H: 1V was used on the inland side to illustrate the maximum impact. In both Options 1 and 2, the grading impacts the existing chain link fence to varying degrees depending on the grade raise of the proposed trail. It is assumed that the existing chain link fence is the property boundary, however the property line should be confirmed upon detailed design. Property impact mitigation is further discussed in Section 6 with the introduction of retaining/toe walls. The crossfall of the trail was set to 3% towards the shore to maintain positive drainage.

City of Hamilton’s Comprehensive Development Guidelines and Financial Policies Manual was followed to ensure the preliminary design of the trail meets the City’s requirements. It should be noted that the profile of the trail was set to a single elevation for the entire corridor for each option and will need to be refined during the detailed design phase to further minimize cost and impact to adjacent lands.

5. Structural

The proposed coastal improvements for the two defined options will require the construction of basic structures to contain the trail raise and fill to be within the property limits and without any encroachment onto adjacent private property. We have carried out preliminary review of the proposed options including all available information and existing site conditions and developed structural systems that will be appropriate to contain the proposed trail profiles for Options 1 and 2-4.

Our initial review indicates that Option 1 has the greater raise above the existing trail and hence would require greater structural considerations including drainage considerations. Our proposed structural design is only preliminary at this stage and the drainage considerations will be addressed in detail during the detailed design.

5.1 Option 1

For Option 1, the grade difference between the proposed trail elevation and the adjacent existing ground (outside of property limits) varies between 0 to 1.4 m. This will require the construction of a retaining wall along this edge to support the raised trail. Our preliminary review and evaluation indicate that a reinforced concrete L-Shaped retaining wall with base slab 1.2 m (minimum frost protection) below the existing ground. The total height of the proposed retaining wall will vary between 1.75 m to 3.00 m. Assuming a soil bearing capacity at the base of the wall as 300 kPa and 200 kPa at Ultimate Limit State (ULS) and Serviceability Limit State (SLS) respectively with the water table assumed to be 1.0 m below the top of the wall, preliminary wall sections are developed and are summarized in Appendix B.

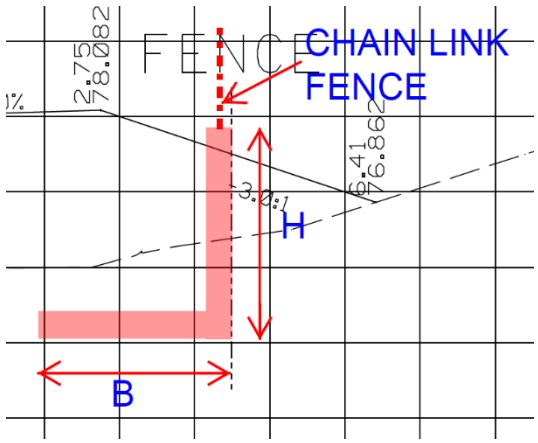

Figure 12: Typical Wall Section – Option 1

5.2 Options 2 - 4

For Option 2, the grade difference between the proposed trail elevation and the adjacent existing ground (outside of property limits) varies between 0 to 0.8 m. Similar to Option 1 above, this will also require the construction of a retaining wall along this edge to support the raised trail. Our preliminary review and evaluation indicate that concrete toe wall or block wall with base 0.50 m below ground would be appropriate for this option. Similar to Option 1, the soil bearing capacity at the base of the wall is assumed as 300 kPa and 200 kPa at Ultimate Limit State (ULS) and Serviceability Limit State (SLS) respectively. Preliminary wall sections are developed and are summarized in Appendix B. Options 2 and 3 would have similar type retaining wall structure.

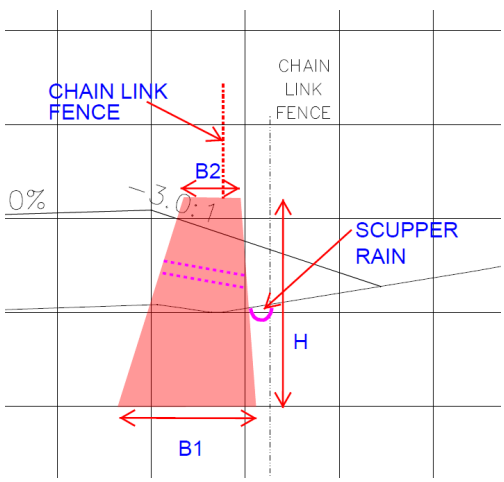

Figure 13: Typical Wall Section – Option 2 (Options 3 and 4 similar)

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6. Cost Estimate

The shoreline protection cost estimate for solution 1 to 4 were based on the following assumptions.

- Volumes were calculated based on typical section for most exposed part of the trail shoreline. Rock volumes and crest elevation will likely be reduced during detailed design.
- Submerged habitat reef volumes were calculated based on the same location of existing artificial islands
- Options 3 and 4 volumes were estimated based on typical section area
- Option 4 volumes considers, conservatively, 50% of Option 4 typical section and 50% of Option 3 section.
- Mobilization / Demobilization was assumed to be 5% of overall construction, considering the large scale of the project.
- 20% contingency was added to the cost.
- 10% engineering fees was added to Option 1 and 20% to Options 2 to 4, due to the significant and unconventional detailed design efforts.

The cost estimate of civil works including earthworks is approximately $700 (average – Option 1) and $600 (average Option 2 to 4) per metre length of trail. Cost includes 20% contingency and 10% engineering fees. Refer to Appendix C for a detailed cost breakdown.

The structural works cost estimate is approximately $3,850 (average – Option 1) and $550 (average – Option 2) per metre length of trail including 20% contingency and 10% engineering fees.

The cost summary for the main design options and alternatives are presented in Table 7. The cost for civil and structural works for Options 2, 3, and 4 are similar as these options have the similar trail profiles.

Table 7: Cost Estimate Summary

Options	Shoreline Protection	Trail (Civil)	Retaining/Toe Wall (Structural)	Total
1	$7,900 / m	$700 / m	$3,850 / m	$12,450 / m
2	$4,500 / m	$600 / m	$550 / m	$5,650 / m
3*	$6,300 / m	$600 / m	$550 / m	$7,450 / m
4	$9,500 / m	$600 / m	$550 / m	$10,650 / m

*** Option 3 preliminary design was refined, and cost estimate of the refined solution is presented in Appendix D**

7. Conclusions

The conceptual solutions to the shoreline protection included metocean assessment of the area of interest, general configuration of the shoreline protection structure to support selection of final solution, and high level cost estimate for each design alternative.

Historical wind and water data were analysed to define the parameters for design criteria. Annual Exceedance Probability of 1:100 was considered to calculate the design water level and wind, these parameters were input to a wind-wave model of Hamilton Harbour to calculate the design wave height.

Considering that almost 50% of the shoreline elevation is under design water level (76.4 m IGDL), the protection solutions include raising the trail to avoid inundation. Solutions including seawalls or headwalls were not considered because of the increased wave energy reflected by steepening the shoreline and the hardening of the shoreline.

Although an increase of trail elevation is considered in the concepts, a freeboard allowance is not included. It is still considered that the trail will receive minimum overtopping volume and it will be structurally able to receive the wave impacts with minor to none damage during extreme conditions.

For each of the proposed options, a retaining wall will be constructed to the west edge of the trail. This wall will protect the trail as well as keep the raised trail within the property limits. Option 1 will require a reinforced concrete L-Shaped wall and concrete toe wall will be required for options 2, 3 and 4.

For all of the proposed options, construction of the trail are the same. However, for Option 1 the proposed trail is significantly higher than the existing trail and therefore requires a greater amount of earth fill.

Table 8 shows a summary of the solutions including advantages and disadvantages of each option. Options 3 and 4 concepts were based on the available reference literature and must be carefully reviewed at detailed design stage.

The cost estimate for each shoreline protection is shown in Table 7. The cost assumed one typical section for Options 2, 3 and 4, the design cost component for those options were higher since further numerical and/or physical modelling and environmental investigation will be necessary.

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Table 8: Summary of the Conceptual Design Alternatives

Options	1	2	3	4
Type	Hard	Hybrid / Soft	Hybrid	Soft
Structure	Conventional revetment with berm	Submerged habitat reef; conventional revetment	Stepped rock revetment	Submerged habitat reef, perched beach
Advantages	› Conventional design based on guidelines; › Expected outcomes / performance	› Increased habitat › Reduction of trail elevation/retaining wall and armour size › Rip rap volume reduction	› Trail elevation/retaining wall reduction › Volume reduction › Public access › Recreation	› Trail elevation/retaining wall reduction › No armour rock at shoreline › Accessible public beach during lower water level › Recreation
Disadvantages	› High trail elevation/retaining wall › Large rock and fill volumes	› Further environmental studies to assess the impact of submerged reef on water quality › Physical or numerical modelling necessary to estimate wave/structure interaction	› Design is based on limited experimental studies using concrete stepped revetments, physical modelling or detailed numerical modelling to define design parameters	› Physical modelling or detailed numerical modelling to define design parameters

8. Recommendations

The solutions proposed for Options 1 to 4 are conceptual and are expected to be developed/ improved during the next design stage, detailed design.

For Option 1, further rock sizing of the armour and filter layers, toe protection, crest elevation refinement and drainage apron dimensions are expected.

For Option 2, other than rock sizing, toe protection and crest refinement, further wave modelling analysis should be considered to take into account the diffraction from the submerged reef and impacts to the shoreline. Since the submerged reef will not be continuous, the wave model will also be used to assess the gap length between the structures and its impacts in the wave climate close to shore. A phase-resolving or similar wave model is recommended. A physical model of the designed structure might also be required to confirm or optimize the dimensions and rock sizing.

Furthermore, the construction of a submerged structure in the Lake will likely result in reduced water circulation. Environmental studies including water quality are recommended to access the impact of the reef on nearshore ecosystem and water quality.

For Option 3, a wave-structure interaction physical or numerical modelling is required to estimate the revetment steps width and height. Similar to Option 1, further rock sizing of the armour and filter layers, toe protection for, drainage and crest refinement should also be done.

For Option 4, the number of sections to construct the perched beach as well as the location of the perched beach need to be identified. Similar to Option 2, environmental assessment is required to study the water quality and the impact on the ecosystem in the nearshore area of the site. In presence of the gravel beach, a phase-resolving wave model is required to model propagation and structures interaction in the nearshore.

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9. References

The following documents provided a basis for the coastal engineering shoreline protection design:

[1] SNC-Lavalin (2019), Langdale Terminal Development – Revetment Area.

[2] SNC-Lavalin (2019), Shoreline Inventory and Assessment of City of Hamilton Owned Assets.

[3] CIRIA, CUR, CETMEF, (2007). The Rock Manual. The Use of Rock in Hydraulic Engineering (2nd Edition). C683, CIRIA, London.

[4] Van der Meer, J.W., Allsop, N.W.H., Bruce, T., De Rouck, J., Kortenhaus, A., Pullen, T.,Schüttrumpf, H.F.R., Troch, P., Zanuttigh, B., (2018). EurOtop. Manual on Wave Overtopping of Sea Defences and Related Structures. An Overtopping Manual Largely Based on European Research, but for Worldwide Application, 2nd Ed.

[5] Hamilton Conservation Authority (2011). Planning & Regulation Policies and Guidelines. Approved by Boards of Directors October 6, 2011

[6] SNC-Lavalin (2019), Condition Assessment and Photo Inventory, City of Hamilton.

[7] Kerpen, N.B., Schoonees, T. and Schlurmann, T., 2019. Wave Overtopping of Stepped Revetments. Water, 11(5), p.1035.

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10. Revision Index and Signatures

Issue Code	Rev. No	Date (yyyy-mm-dd)	Description of Changes	Initials
RR	PA	2020-01-13	Draft Issued for Client Review	NC
RI	PB	2020-04-07	Attending Comments	MA-N
RI	R0	2020-07-16	Final	GMJ

Issue Codes:

RC Released for Construction
RD Released for Design
RF Released for Fabrication
RI Released for Information
RP Released for Purchase
RQ Released for Quotation
RR Released for Review and Comments

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Civil EIT, Roads & Utilities

Vaikun Nadarajah. P.Eng.
Structural Engineer

Reviewed By:

LICENSED PROFESSIONAL ENGINEER
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Senior Coastal Engineer

Norton Chu, P. Eng.
Civil Lead, Roads & Utilities

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Approved By:

LICENSED PROFESSIONAL ENGINEER
M. ASANTE-NIMAKO
July 21, 2020
PROVINCE OF ONTARIO

Michael Asante-Nimako, P. Eng.
Manager Structures

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Appendix A

Option 1 and Option 2

Conceptual Plan and Profile Drawings

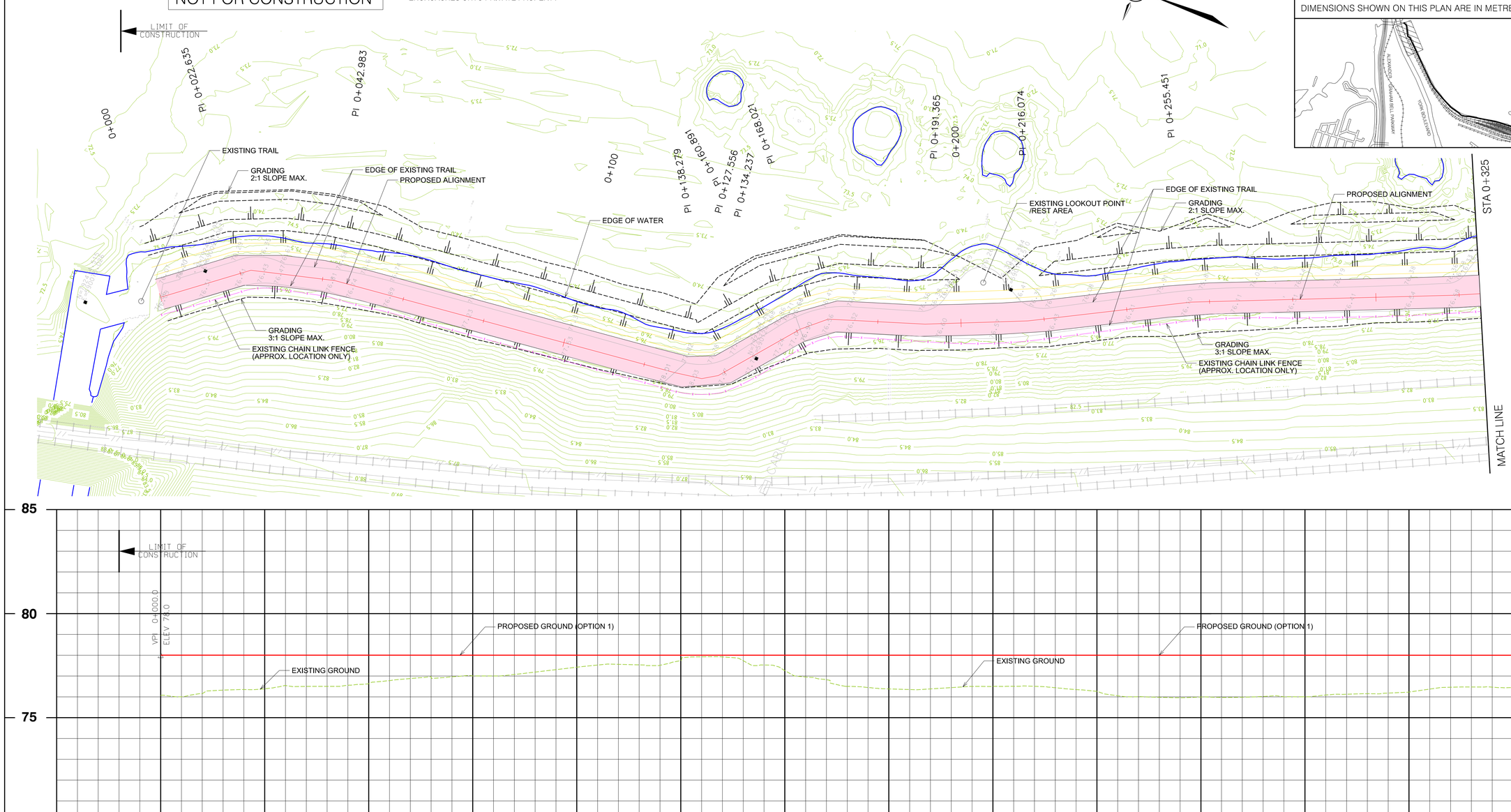
Conceptual Cross Sections

HAMILTON HARBOUR WATERFRONT TRAIL

PRELIMINARY
NOT FOR CONSTRUCTION

DESIGN NOTE:
RETAINING WALL TO BE PROPOSED AT LOCATIONS WHERE GRADING ENCROACHES ONTO PRIVATE PROPERTY

DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED



PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL PROFILE ELEVATIONS	76.1	76.4	76.6	77.0	77.4	77.7	77.3	76.4	76.5	76.3	76.0	76.0	76.2	76.5	EXISTING ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	0+000	0+025	0+050	0+075	0+100	0+125	0+150	0+175	0+200	0+225	0+250	0+275	0+300	0+325	EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
HORIZONTAL 1:500 (0, 5m, 10m, 20m)
VERTICAL 1:100 (0, 1m, 2m, 4m)

DESIGNER
Jason Park

PROJECT ENGINEER
Norton Chu, P. Eng.

CITY OF HAMILTON
Public Works Department

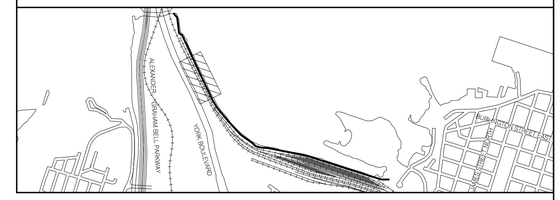
HAMILTON HARBOUR WATERFRONT TRAIL
OPTION 1 - SHORELINE PROTECTION (PROP. ELEV.: 78.0m)
From : STATION 0+000
To : STATION 0+325

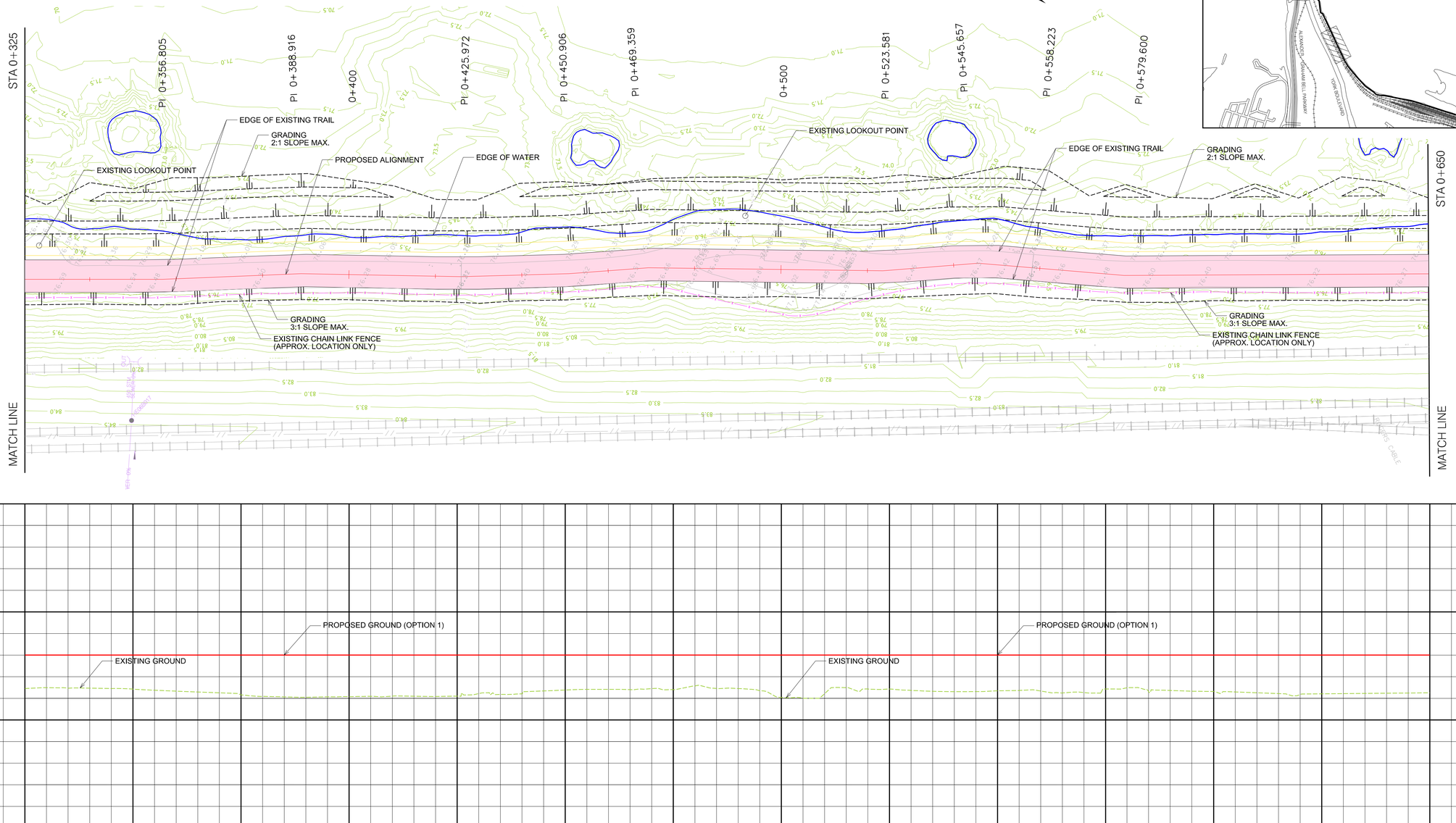
HAMILTON HARBOUR WATERFRONT TRAIL

PRELIMINARY
NOT FOR CONSTRUCTION

DESIGN NOTE:
RETAINING WALL TO BE PROPOSED AT LOCATIONS WHERE GRADING ENCROACHES ONTO PRIVATE PROPERTY

DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED





PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL PROFILE ELEVATIONS	76.5	76.4	76.2	76.1	76.1	76.4	76.4	76.0	76.4	76.3	76.4	76.3	76.2	76.3	EXISTING ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	0+325	0+350	0+375	0+400	0+425	0+450	0+475	0+500	0+525	0+550	0+575	0+600	0+625	0+650	EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
HORIZONTAL 1:500 (0, 5m, 10m, 20m)
VERTICAL 1:100 (0, 1m, 2m, 4m)

DESIGNER
Jason Park

PROJECT ENGINEER
Norton Chu, P. Eng.

CITY OF HAMILTON
Public Works Department

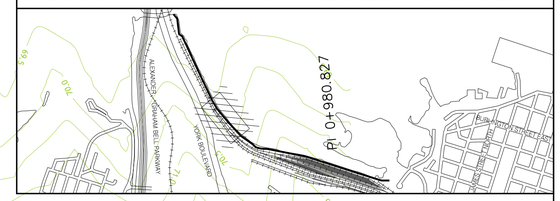
HAMILTON HARBOUR WATERFRONT TRAIL
OPTION 1 - SHORELINE PROTECTION (PROP. ELEV.: 78.0m)
From : STATION 0+325
To : STATION 0+650

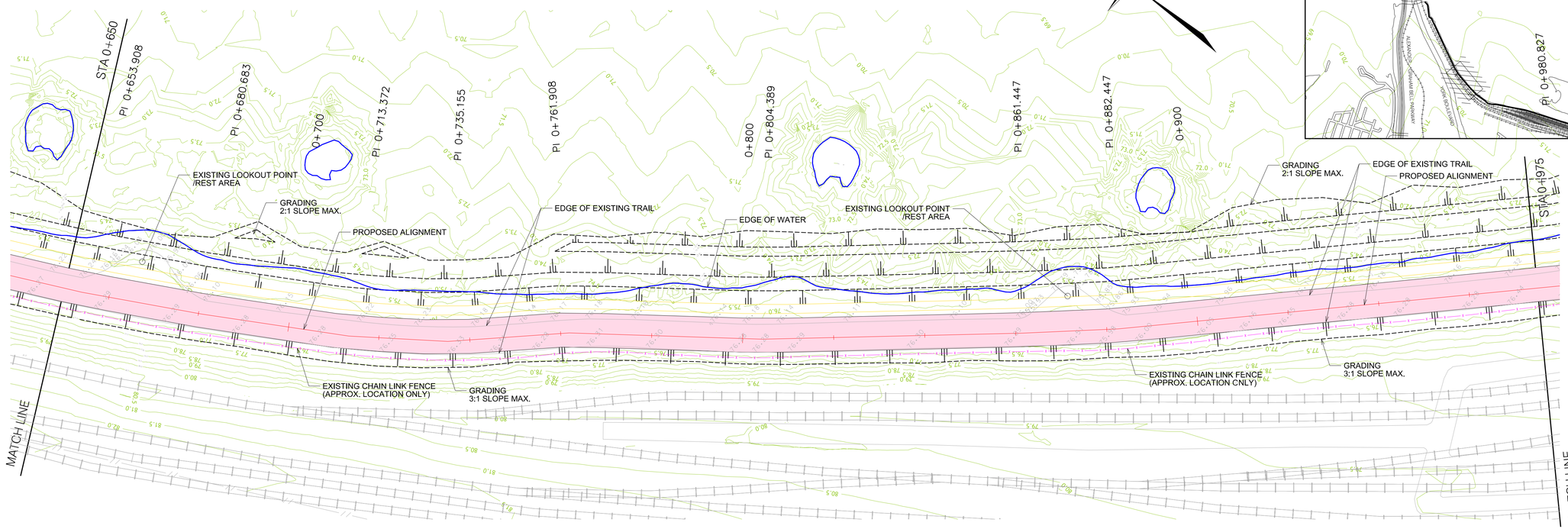
HAMILTON HARBOUR WATERFRONT TRAIL

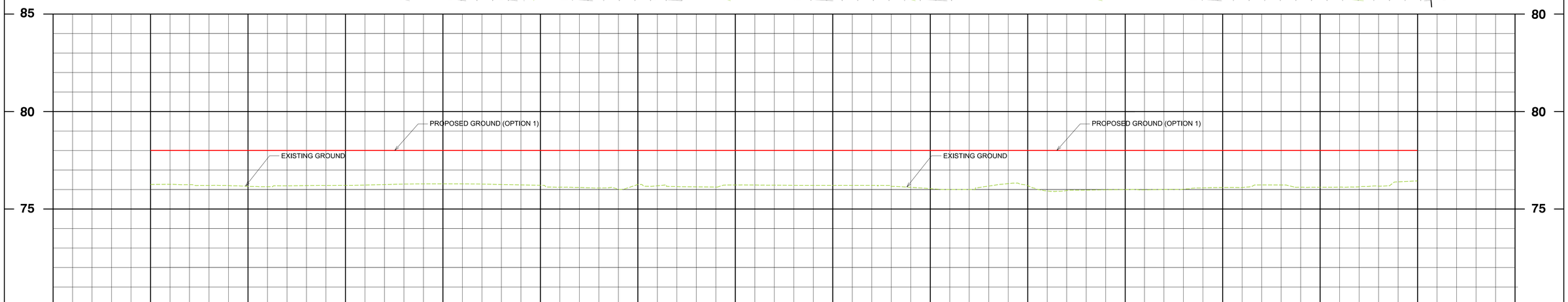
PRELIMINARY
NOT FOR CONSTRUCTION

DESIGN NOTE:
RETAINING WALL TO BE PROPOSED AT LOCATIONS WHERE GRADING ENCROACHES ONTO PRIVATE PROPERTY

DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED







PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS
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EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	0+650	0+675	0+700	0+725	0+750	0+775	0+800	0+825	0+850	0+875	0+900	0+925	0+950	0+975	EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
HORIZONTAL 1:500 (0, 5m, 10m, 20m)
VERTICAL 1:100 (0, 1m, 2m, 4m)

DESIGNER
Jason Park

PROJECT ENGINEER
Norton Chu, P. Eng.

CITY OF HAMILTON
Public Works Department

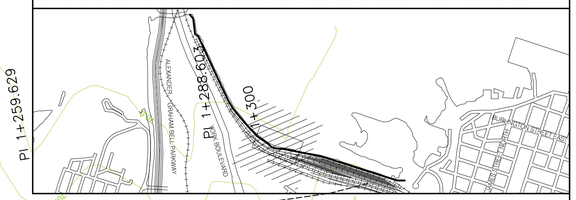
HAMILTON HARBOUR WATERFRONT TRAIL
OPTION 1 - SHORELINE PROTECTION (PROP. ELEV.: 78.0m)
From : STATION 0+650
To : STATION 0+975

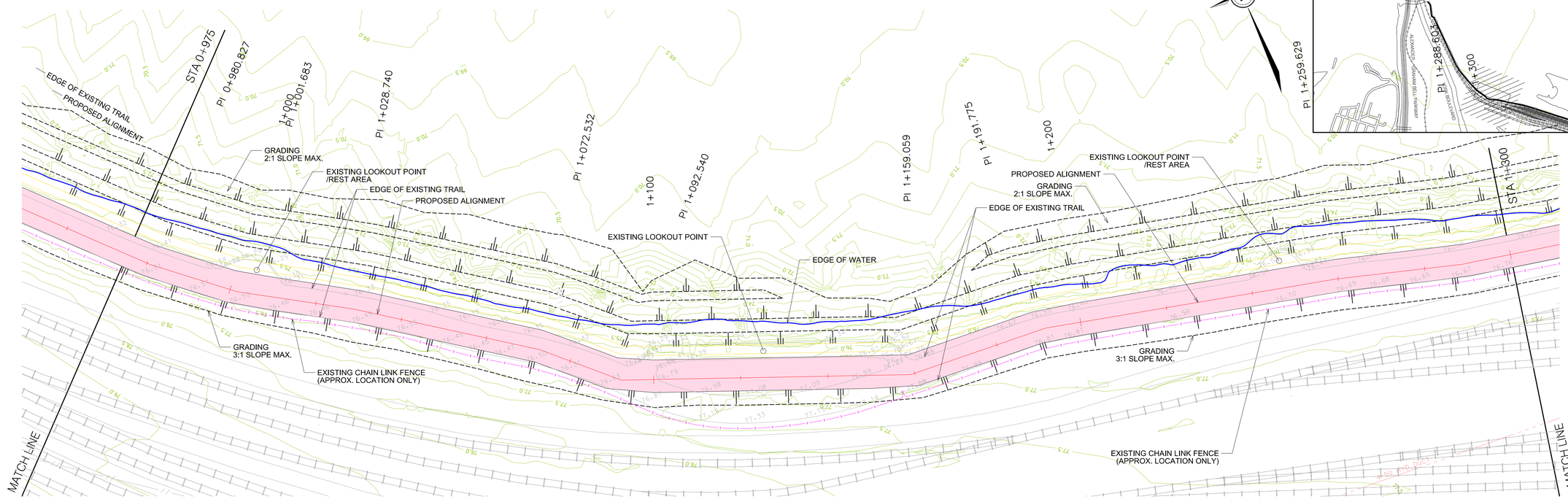
HAMILTON HARBOUR WATERFRONT TRAIL

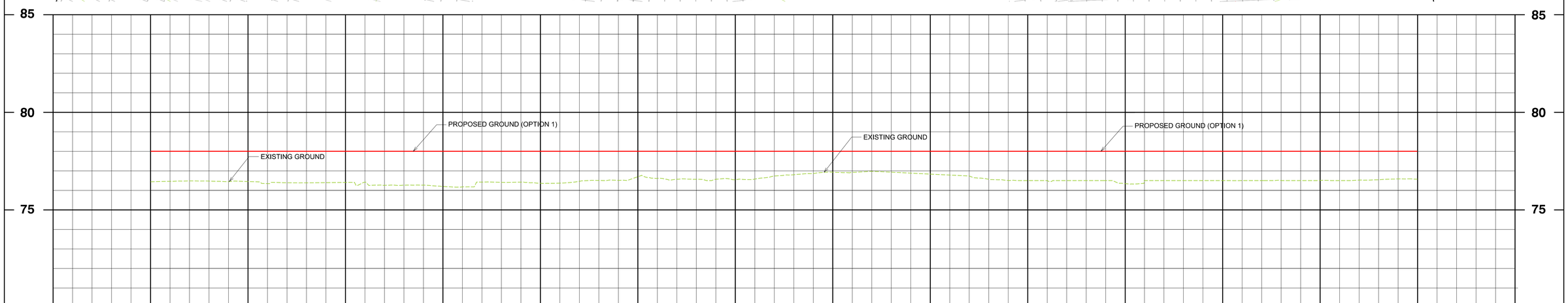
PRELIMINARY
NOT FOR CONSTRUCTION

DESIGN NOTE:
RETAINING WALL TO BE PROPOSED AT LOCATIONS WHERE GRADING ENCROACHES ONTO PRIVATE PROPERTY

DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED







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EXISTING ℄ OF TRAIL PROFILE ELEVATIONS	76.4	76.4	76.4	76.2	76.4	76.7	76.5	76.9	76.8	76.5	76.3	76.5	76.5	76.6	EXISTING ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	0+975	1+000	1+025	1+050	1+075	1+100	1+125	1+150	1+175	1+200	1+225	1+250	1+275	1+300	EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
HORIZONTAL 1:500 (0, 5m, 10m, 20m)
VERTICAL 1:100 (0, 1m, 2m, 4m)

DESIGNER
Jason Park

PROJECT ENGINEER
Norton Chu, P. Eng.

CITY OF HAMILTON
Public Works Department

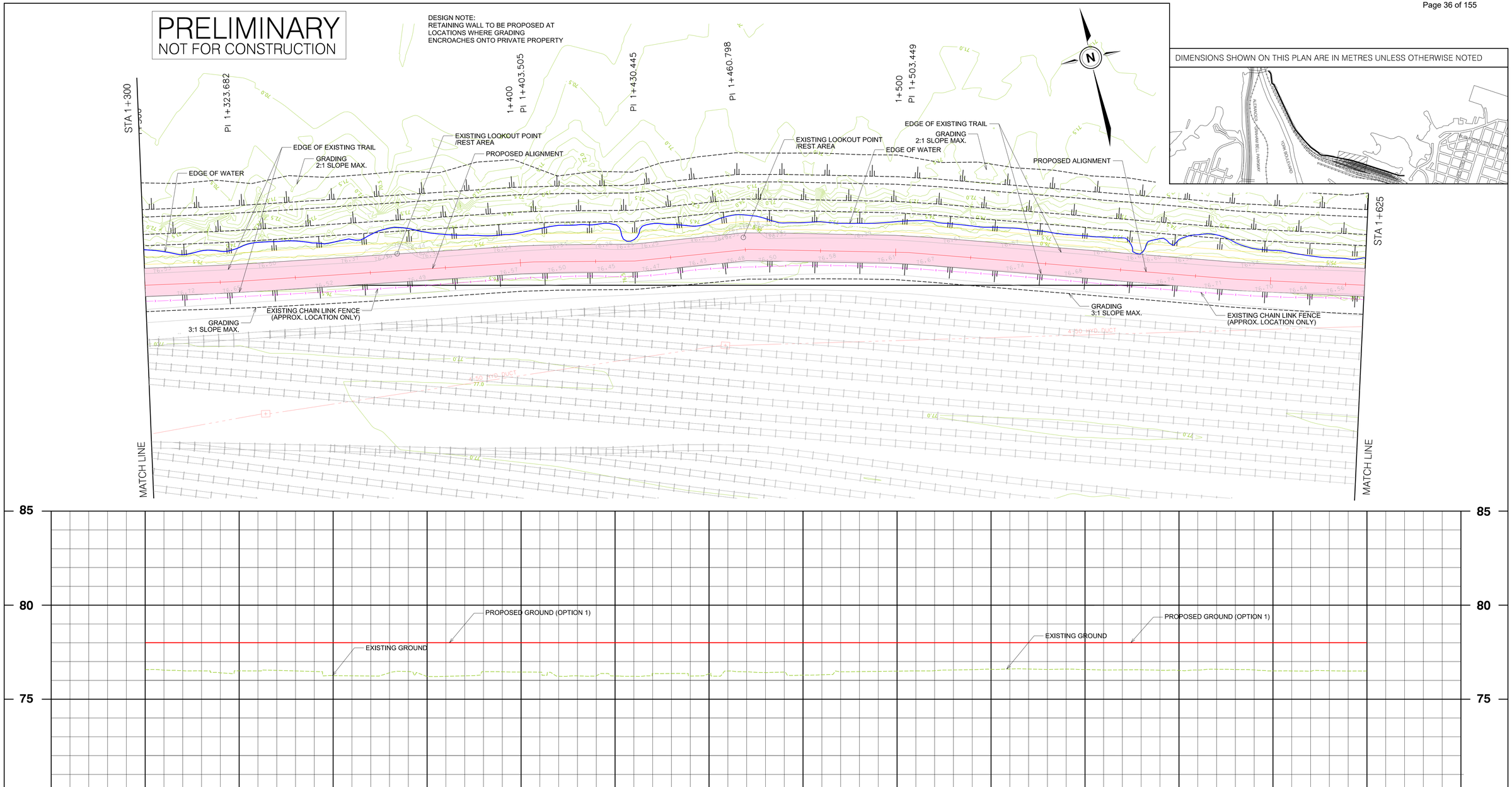
HAMILTON HARBOUR WATERFRONT TRAIL
OPTION 1 - SHORELINE PROTECTION (PROP. ELEV.: 78.0m)
From : STATION 0+975
To : STATION 1+300

HAMILTON HARBOUR WATERFRONT TRAIL

PRELIMINARY
NOT FOR CONSTRUCTION

DESIGN NOTE:
RETAINING WALL TO BE PROPOSED AT LOCATIONS WHERE GRADING ENCROACHES ONTO PRIVATE PROPERTY

DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED



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EXISTING ℄ OF TRAIL PROFILE ELEVATIONS	76.6	76.5	76.2	76.2	76.4	76.2	76.4	76.3	76.5	76.6	76.6	76.5	76.5	76.5	EXISTING ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	1+300	1+325	1+350	1+375	1+400	1+425	1+450	1+475	1+500	1+525	1+550	1+575	1+600	1+625	EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
HORIZONTAL 1:500 (0, 5m, 10m, 20m)
VERTICAL 1:100 (0, 1m, 2m, 4m)

DESIGNER
Jason Park

PROJECT ENGINEER
Norton Chu, P. Eng.

CITY OF HAMILTON
Public Works Department

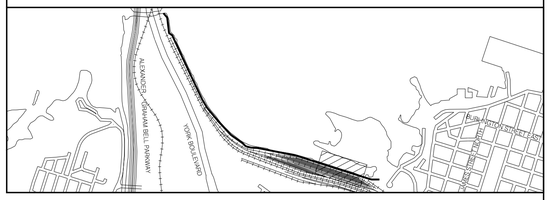
HAMILTON HARBOUR WATERFRONT TRAIL
OPTION 1 - SHORELINE PROTECTION (PROP. ELEV.: 78.0m)
From : STATION 1+300
To : STATION 1+625

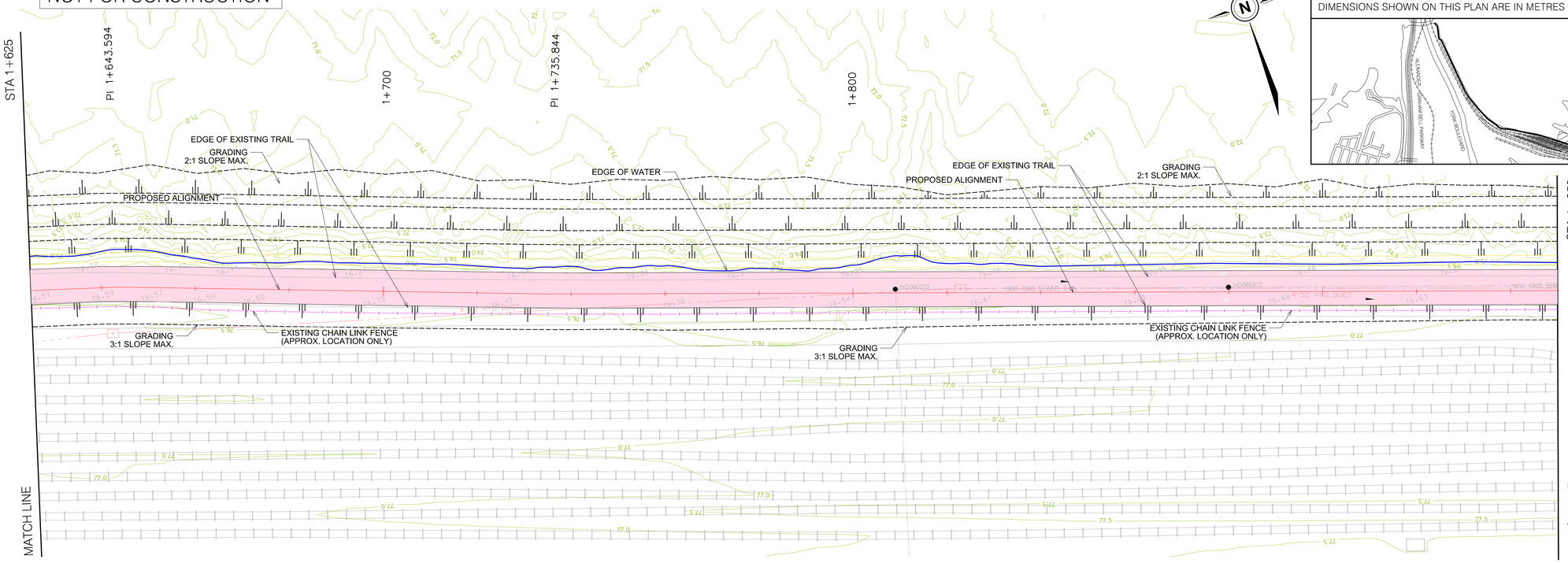
HAMILTON HARBOUR WATERFRONT TRAIL

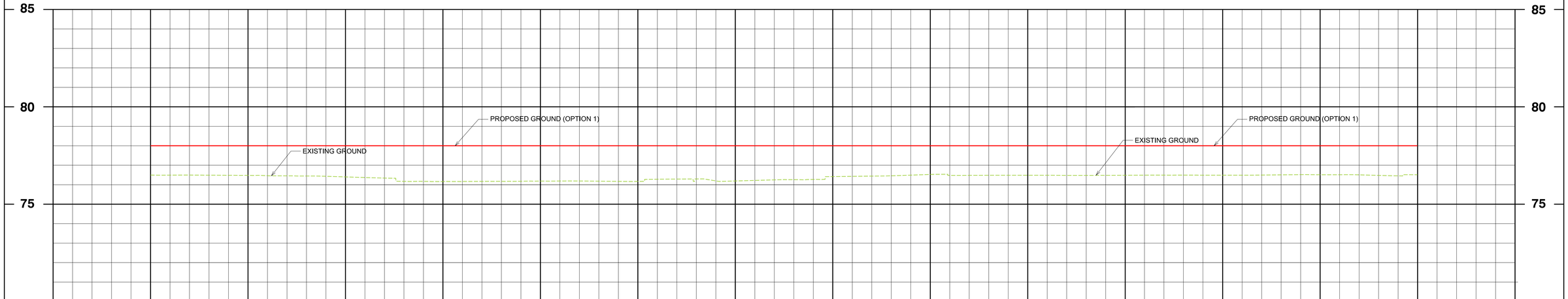
PRELIMINARY
NOT FOR CONSTRUCTION

DESIGN NOTE:
RETAINING WALL TO BE PROPOSED AT LOCATIONS WHERE GRADING ENCROACHES ONTO PRIVATE PROPERTY

DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED







PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	78.0	PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL PROFILE ELEVATIONS	76.5	76.5	76.4	76.2	76.2	76.2	76.2	76.4	76.5	76.5	76.5	76.5	76.5	76.5	EXISTING ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	1+625	1+650	1+675	1+700	1+725	1+750	1+775	1+800	1+825	1+850	1+875	1+900	1+925	1+950	EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
HORIZONTAL 1:500 (0, 5m, 10m, 20m)
VERTICAL 1:100 (0, 1m, 2m, 4m)

DESIGNER
Stephen McDonald

PROJECT ENGINEER
Norton Chu, P. Eng.

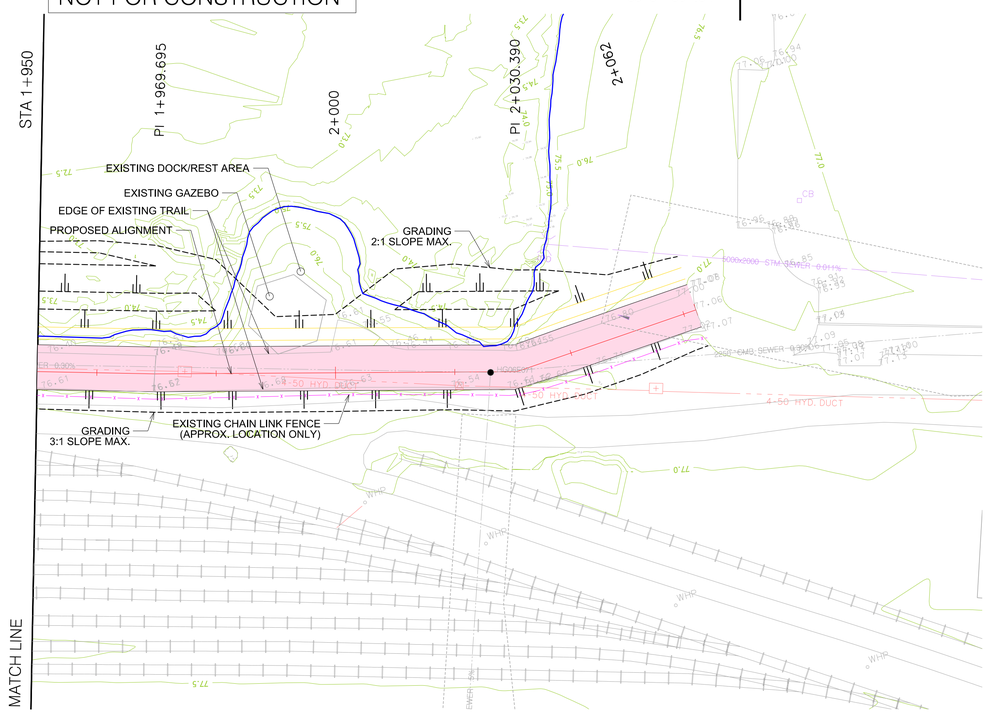
CITY OF HAMILTON
Public Works Department

HAMILTON HARBOUR WATERFRONT TRAIL
OPTION 1 - SHORELINE PROTECTION (PROP. ELEV.: 78.0m)
From : STATION 1+625
To : STATION 1+950

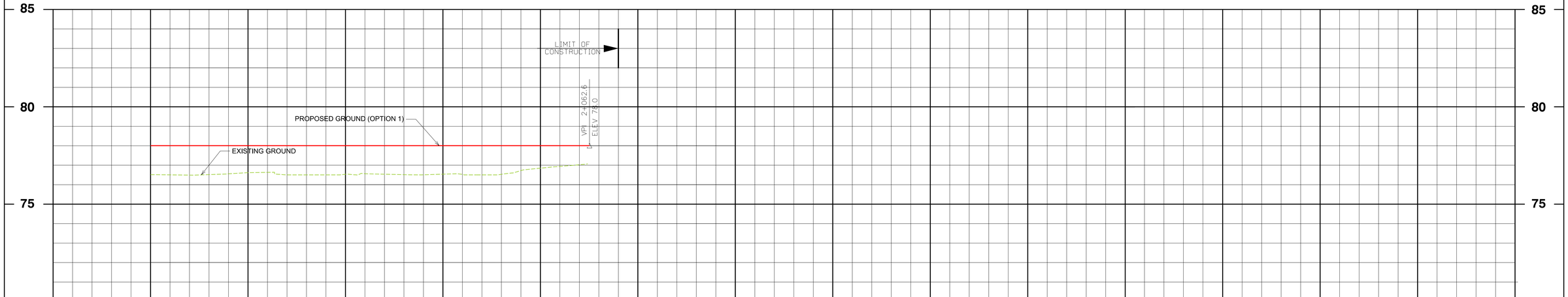
HAMILTON HARBOUR WATERFRONT TRAIL

PRELIMINARY
NOT FOR CONSTRUCTION

DESIGN NOTE:
RETAINING WALL TO BE PROPOSED AT LOCATIONS WHERE GRADING ENCROACHES ONTO PRIVATE PROPERTY



DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED



PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS	78.0	78.0	78.0	78.0	78.0			PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL PROFILE ELEVATIONS	76.5	76.6	76.5	76.5	76.8			EXISTING ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	1+950	1+975	2+000	2+025	2+050	2+075	2+100	EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
HORIZONTAL 1:500 (0, 5m, 10m, 20m)
VERTICAL 1:100 (0, 1m, 2m, 4m)

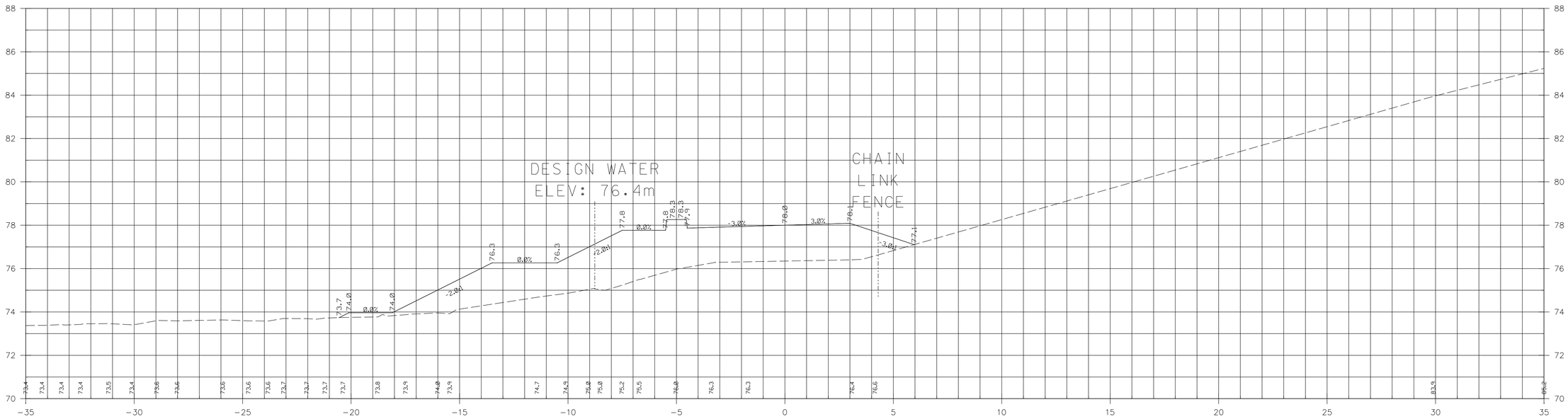
DESIGNER
Stephen McDonald

PROJECT ENGINEER
Norton Chu, P. Eng.

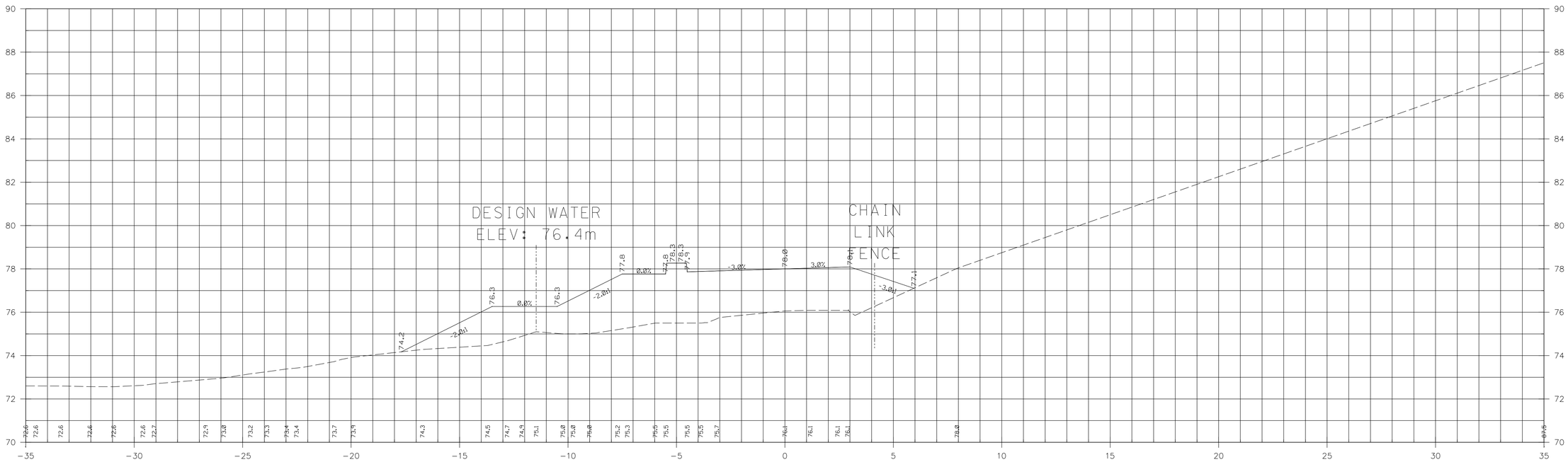
CITY OF HAMILTON
Public Works Department

HAMILTON HARBOUR WATERFRONT TRAIL
OPTION 1 - SHORELINE PROTECTION (PROP. ELEV.: 78.0m)
From : STATION 1+950
To : STATION 2+070

SCALE: 1:100 STA 0+000.00 TO STA 0+020.00

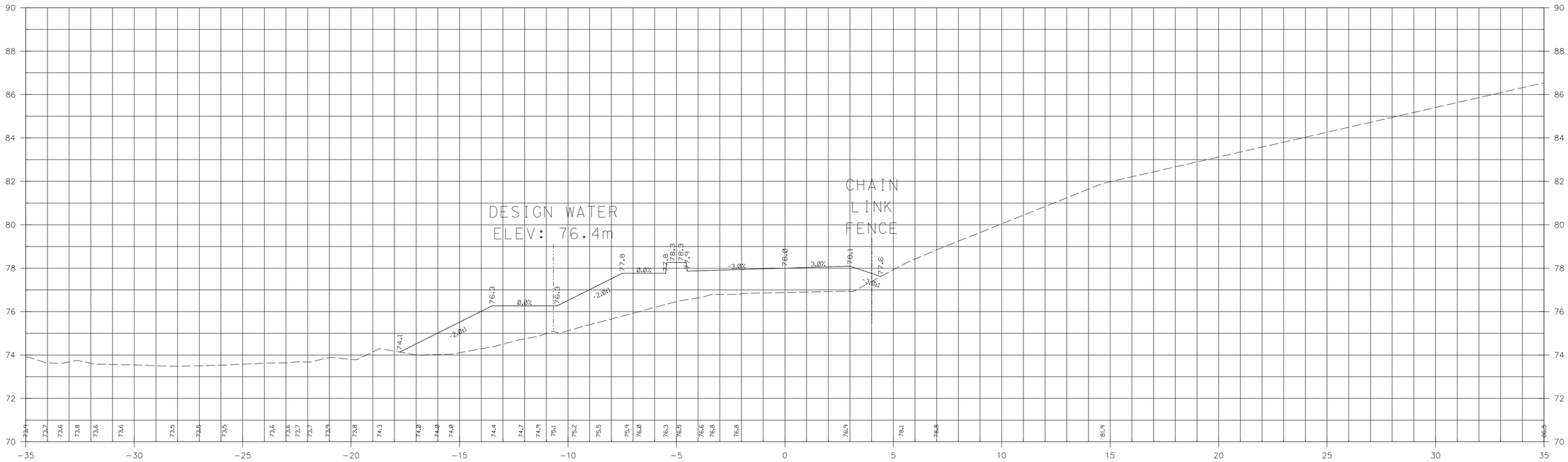


0+020.00

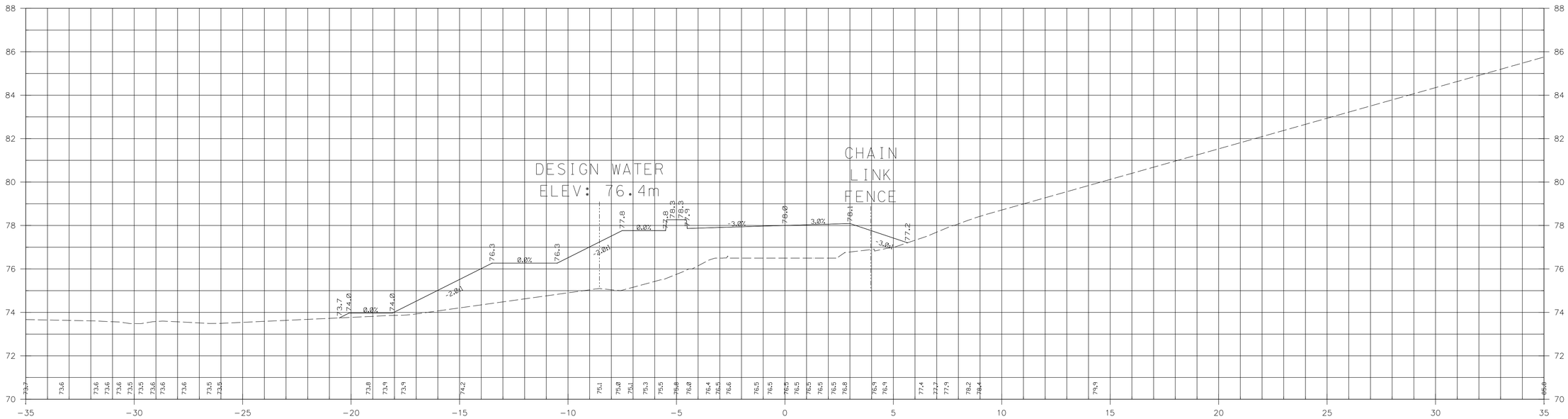


0+000.00

SCALE: 1:100 STA 0+040.00 TO STA 0+060.00

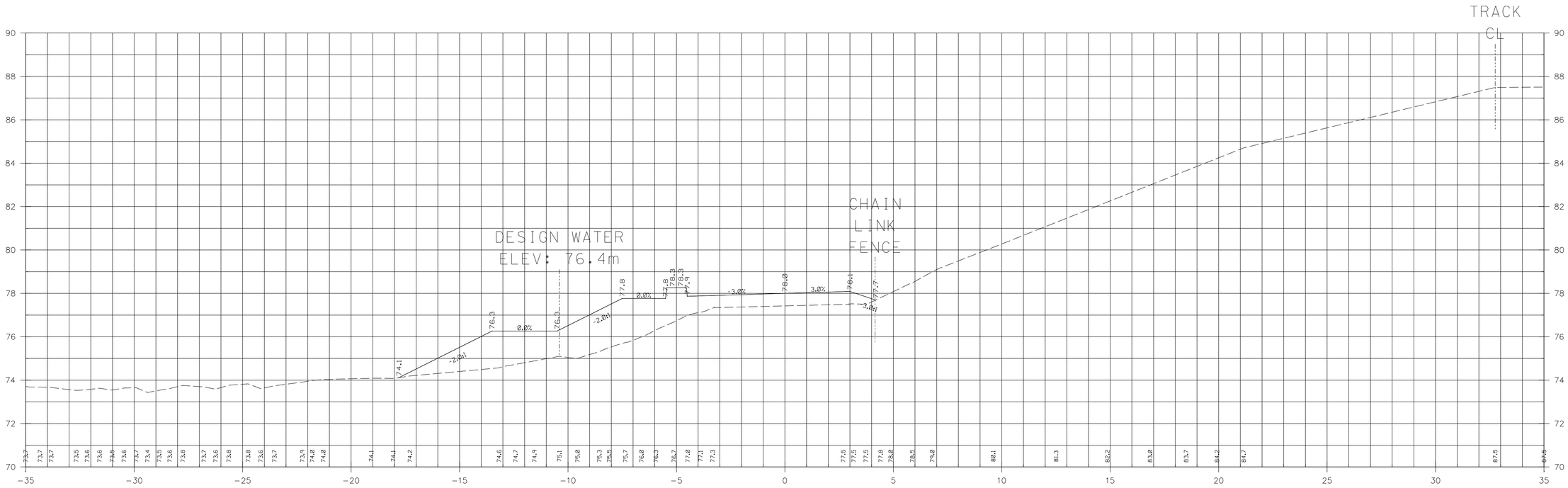


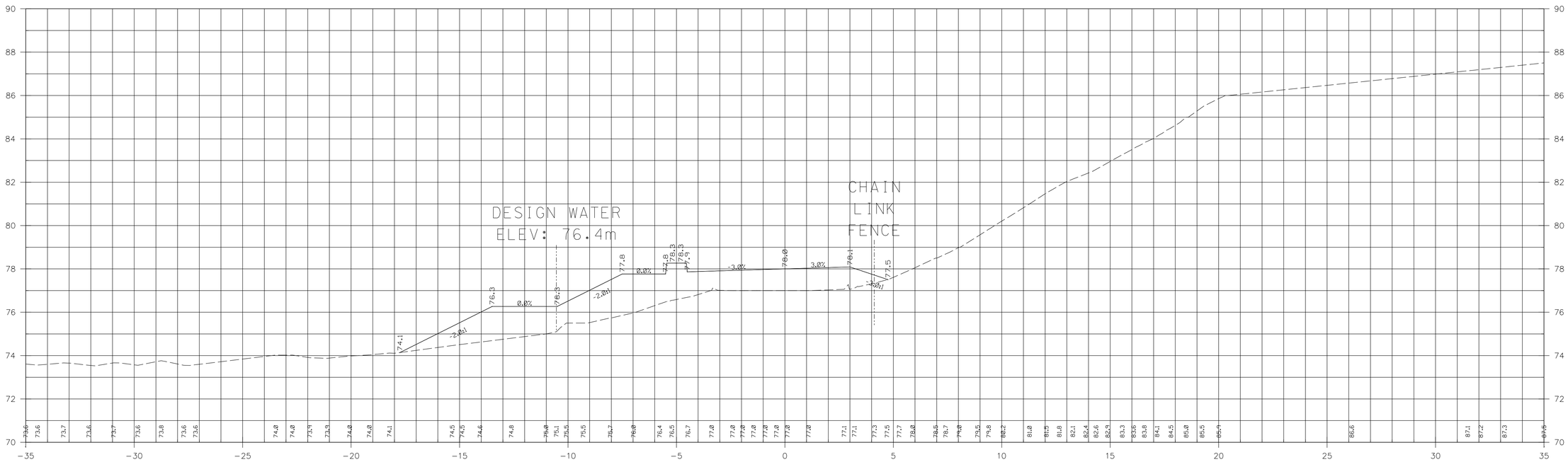
0+060.00



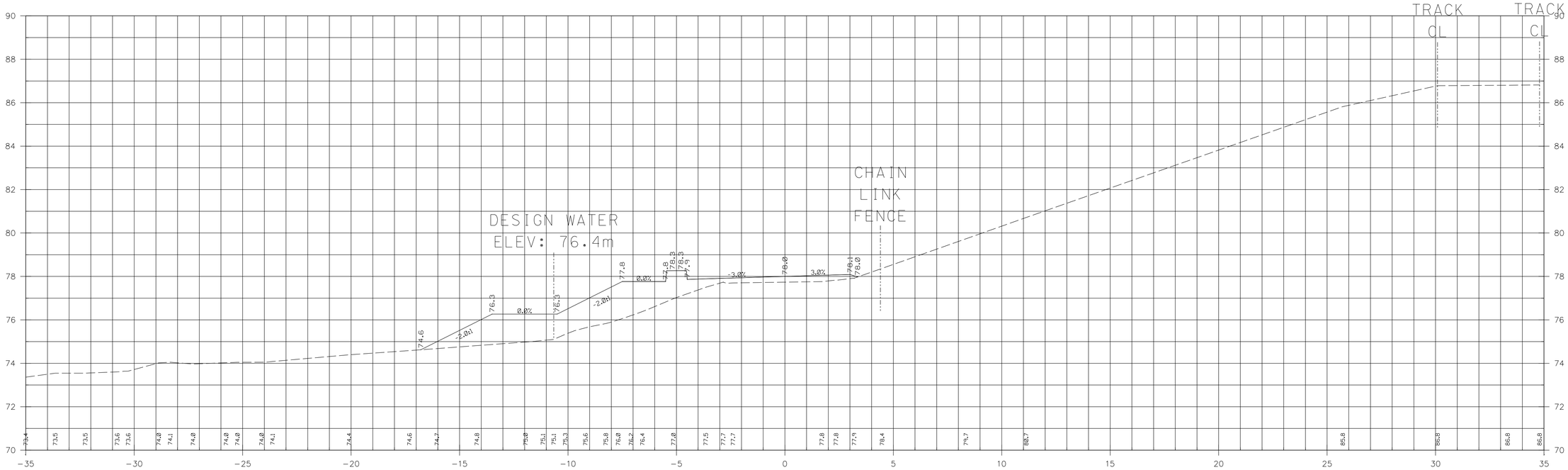
0+040.00

SCALE: 1:100 STA 0+080.00 TO STA 0+100.00

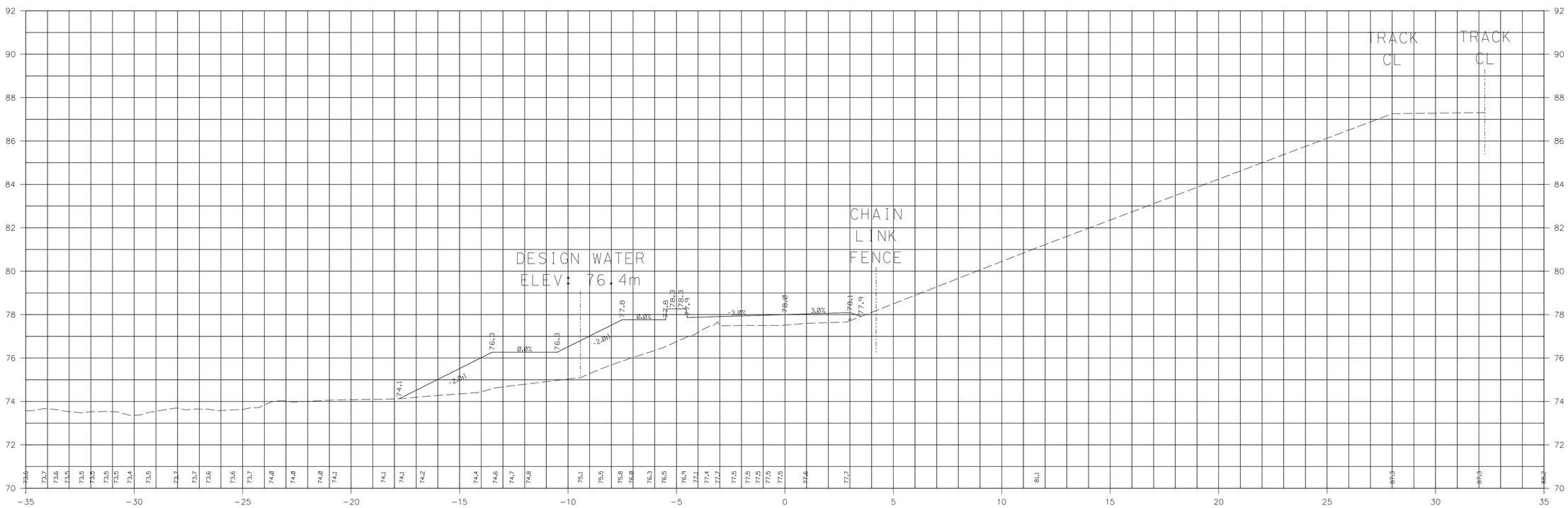




SCALE: 1:100 STA 0+120.00 TO STA 0+140.00



0+140.00



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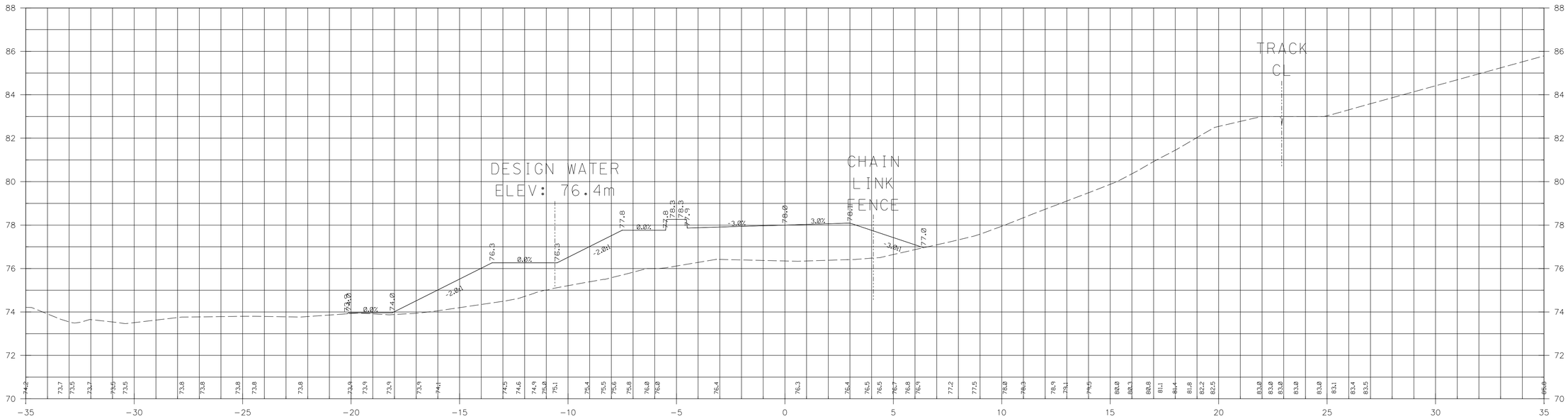
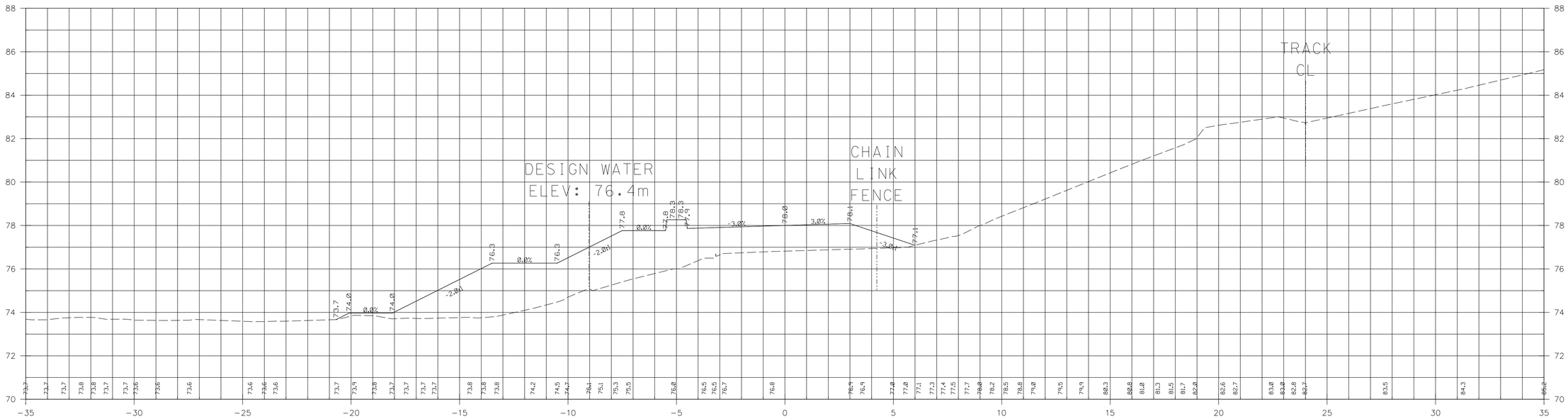
SCALE: 1:100 STA 0+160.00 TO STA 0+180.00

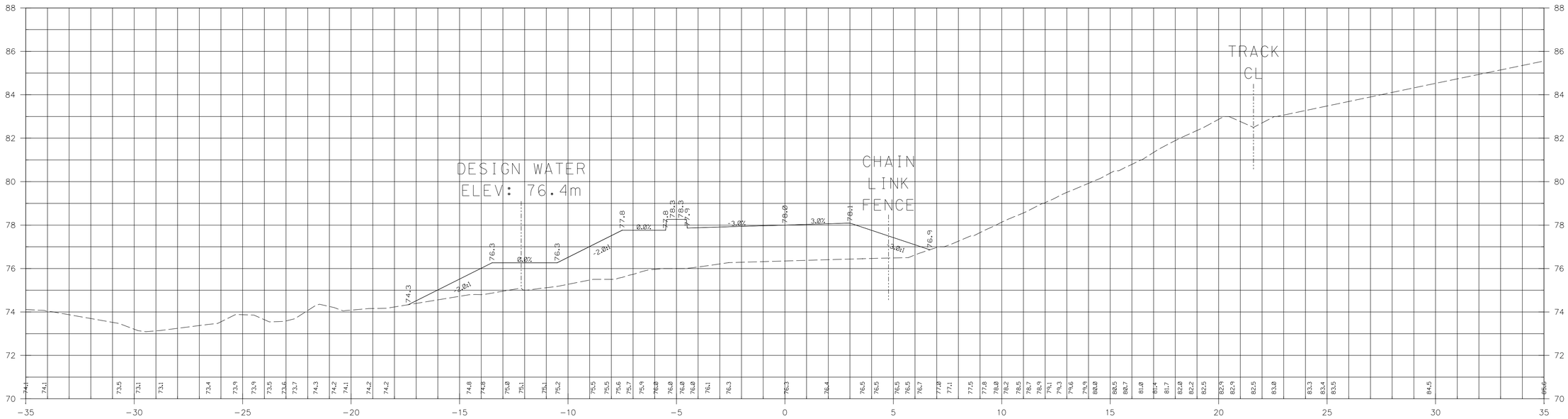


0+180.00

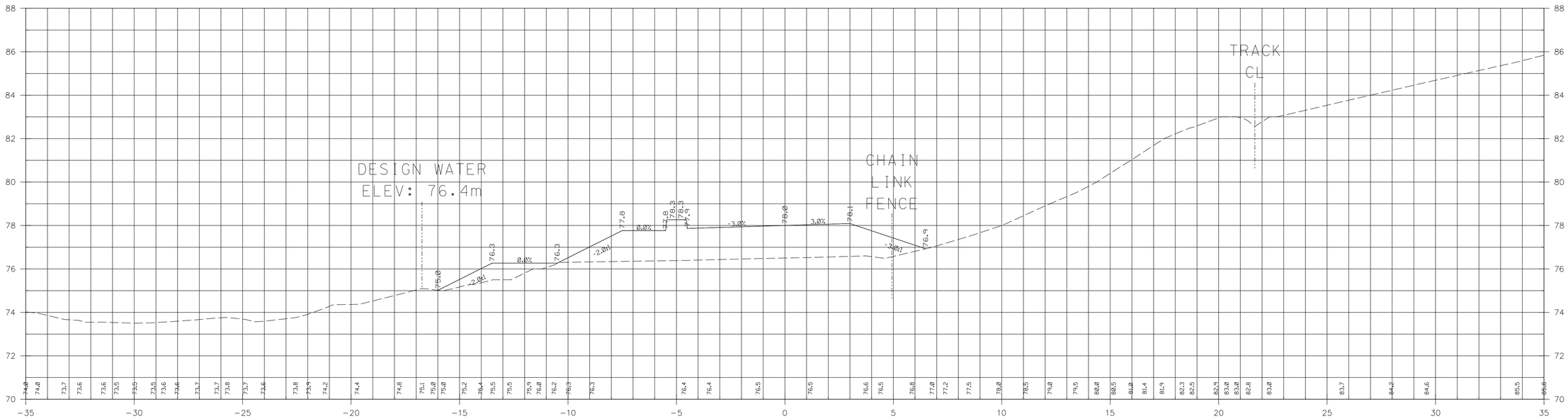


0+160.00

SCALE: 1:100 STA 0+200.00 TO STA 0+220.00

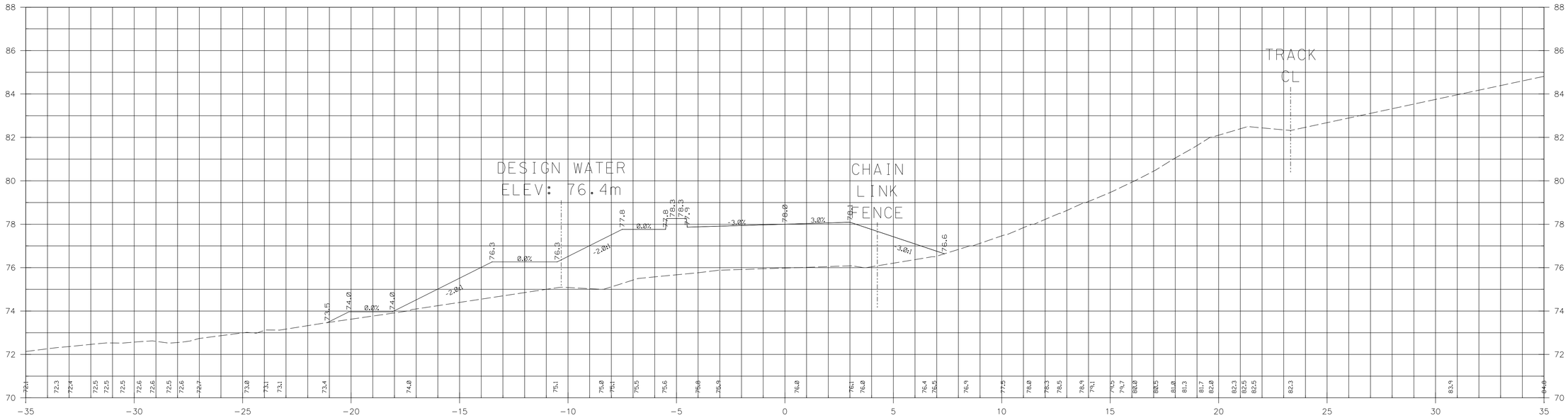


0+220.00



0+200.00

SCALE: 1:100 STA 0+240.00 TO STA 0+260.00



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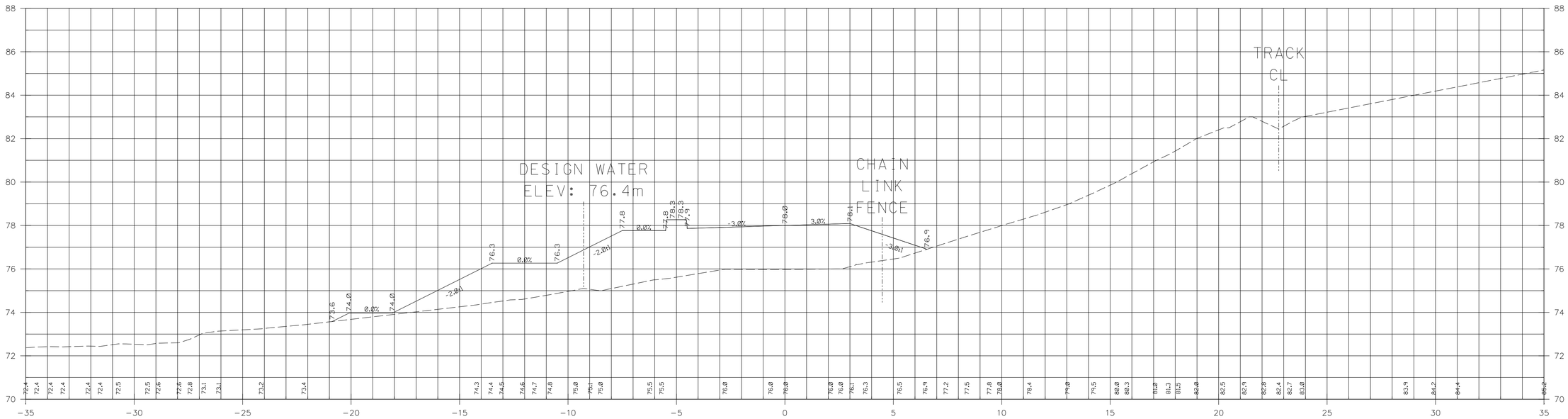

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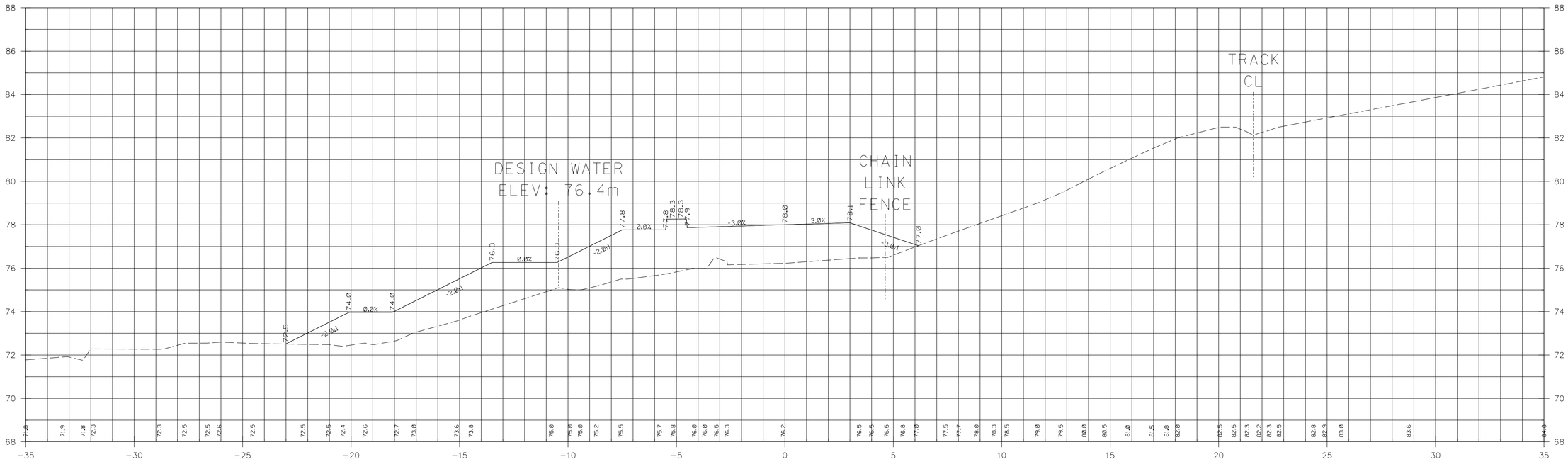
SCALE: 1:100 STA 0+280.00 TO STA 0+300.00



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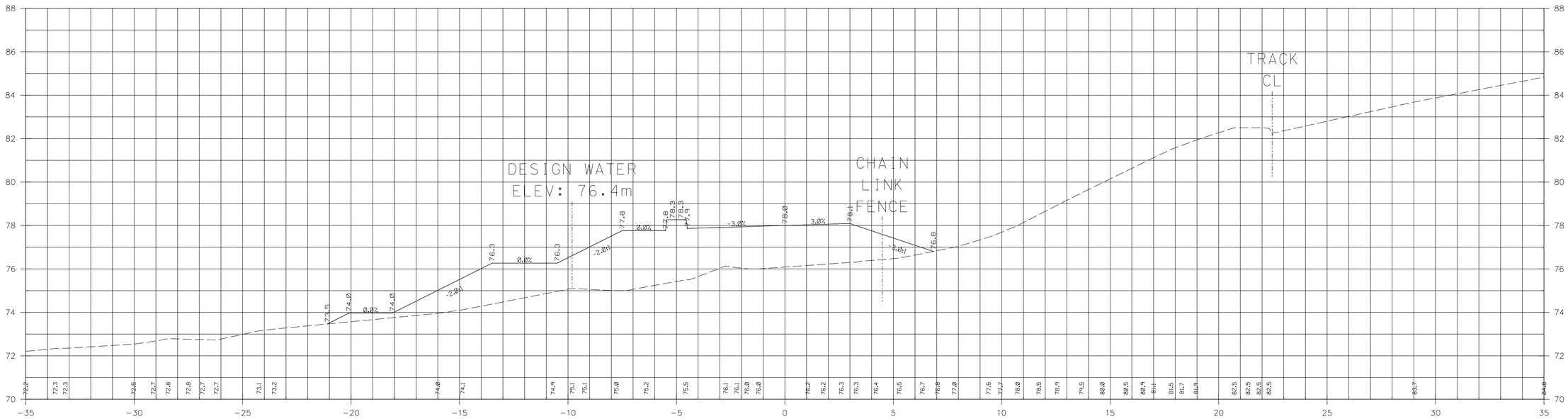
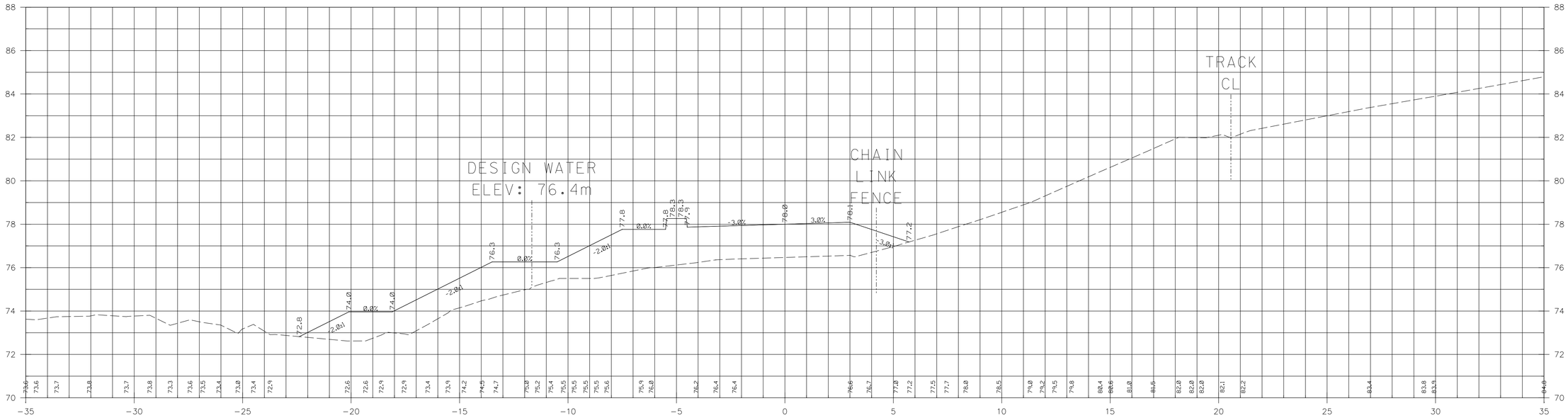


0+280.00

SCALE: 1:100 STA 0+320.00 TO STA 0+340.00



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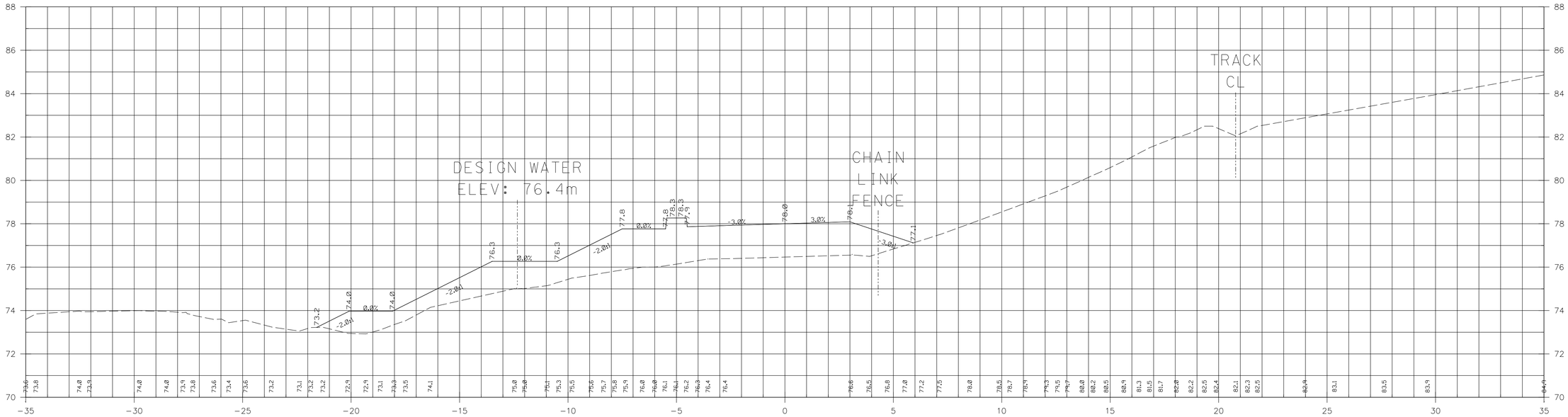

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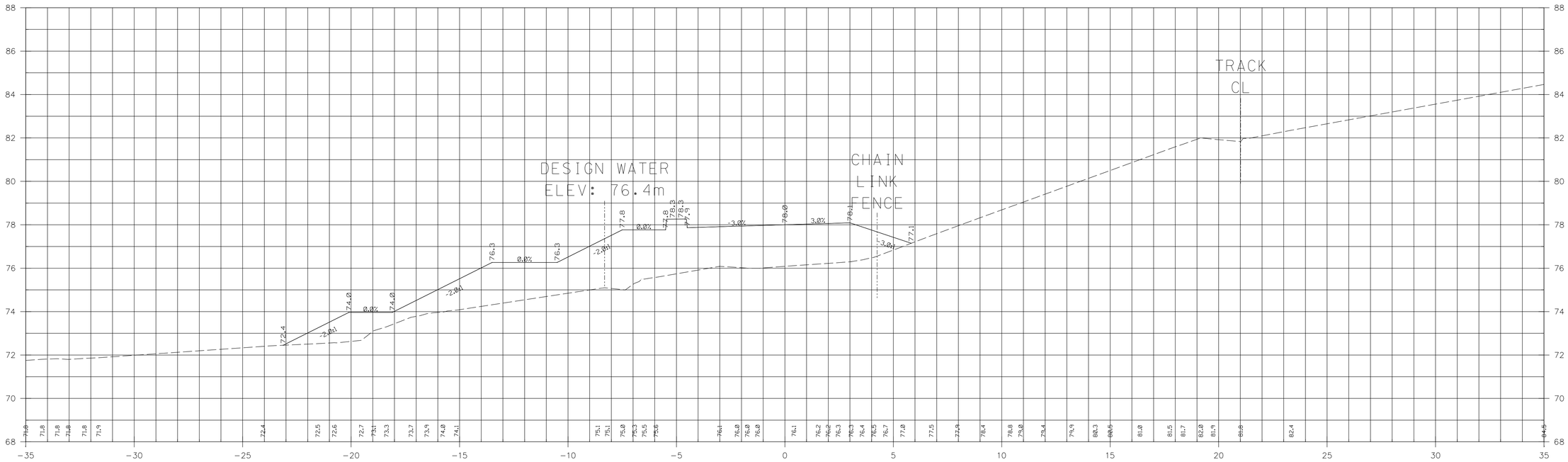
SCALE: 1:100 STA 0+360.00 TO STA 0+380.00



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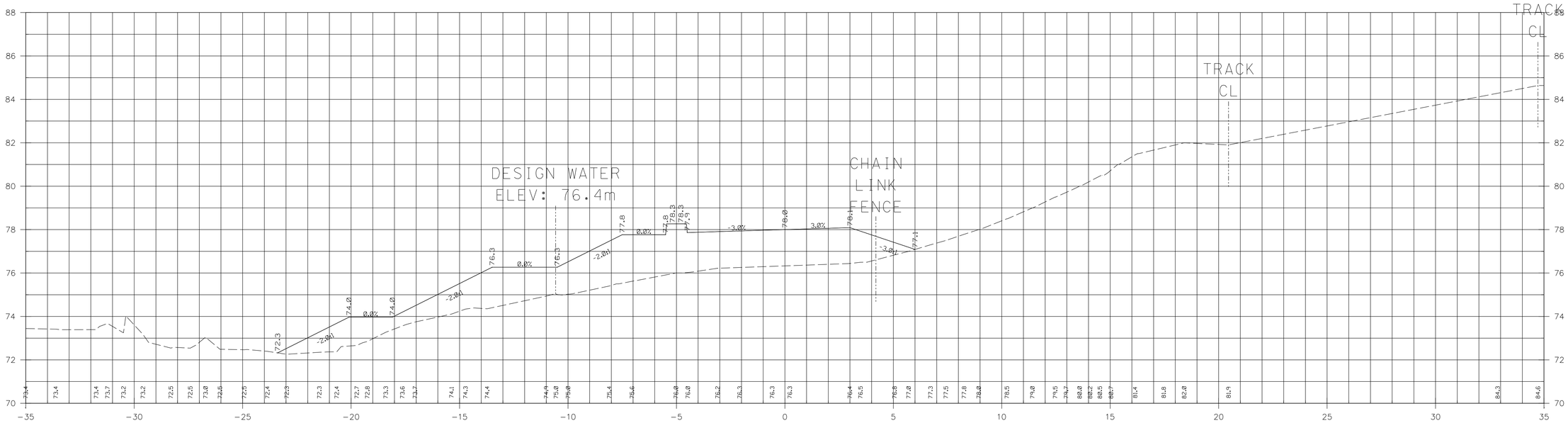

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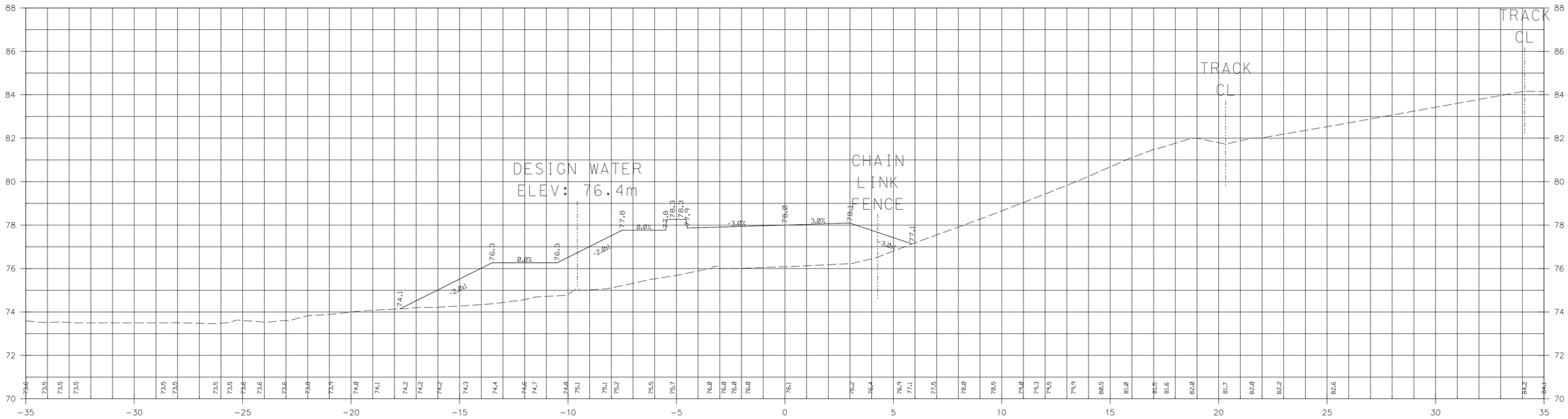
SCALE: 1:100 STA 0+400.00 TO STA 0+420.00



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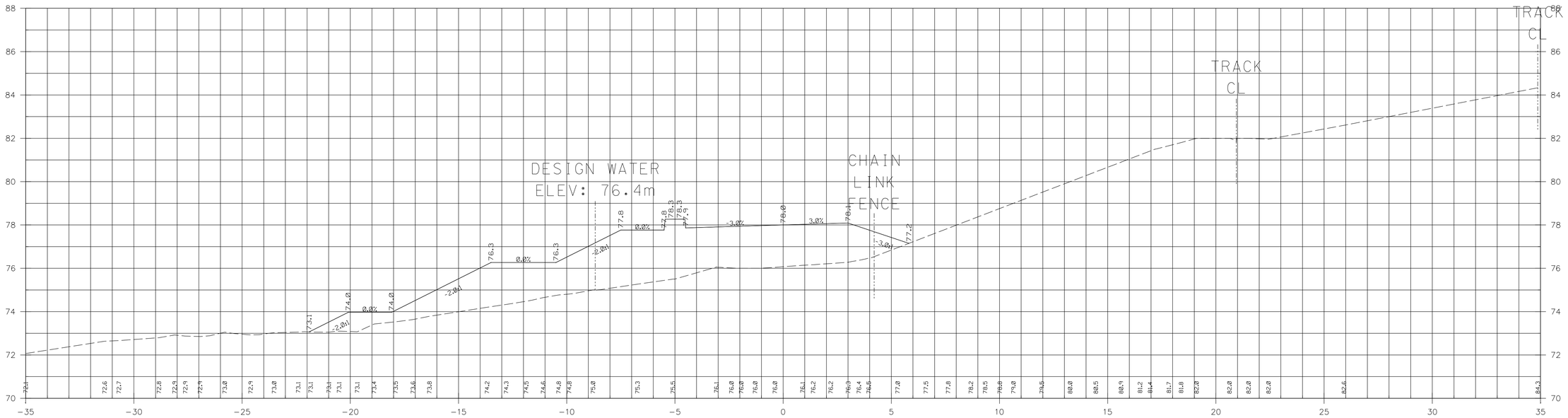

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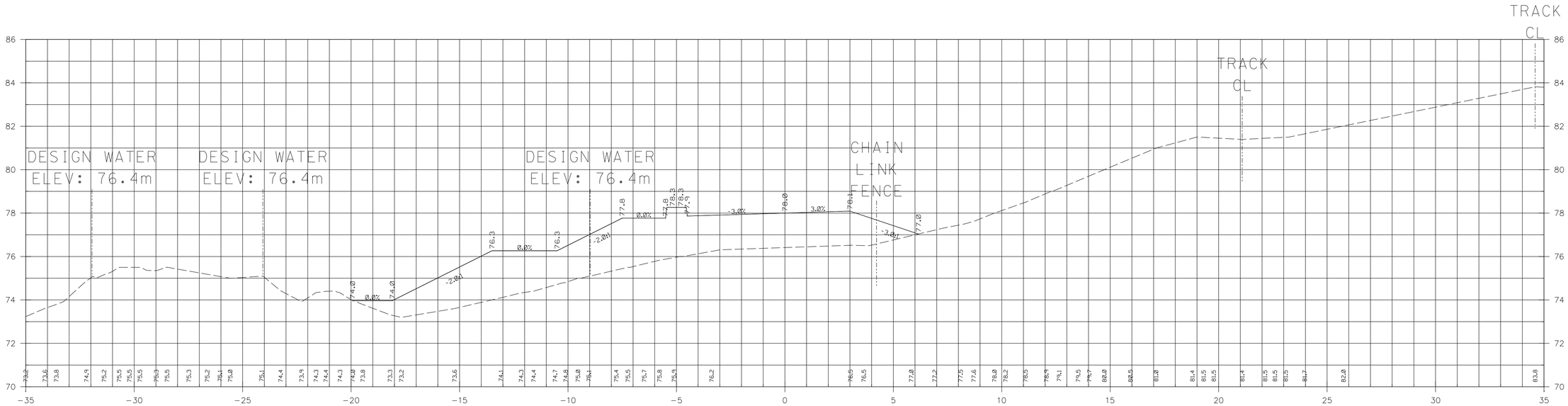
SCALE: 1:100 STA 0+440.00 TO STA 0+460.00



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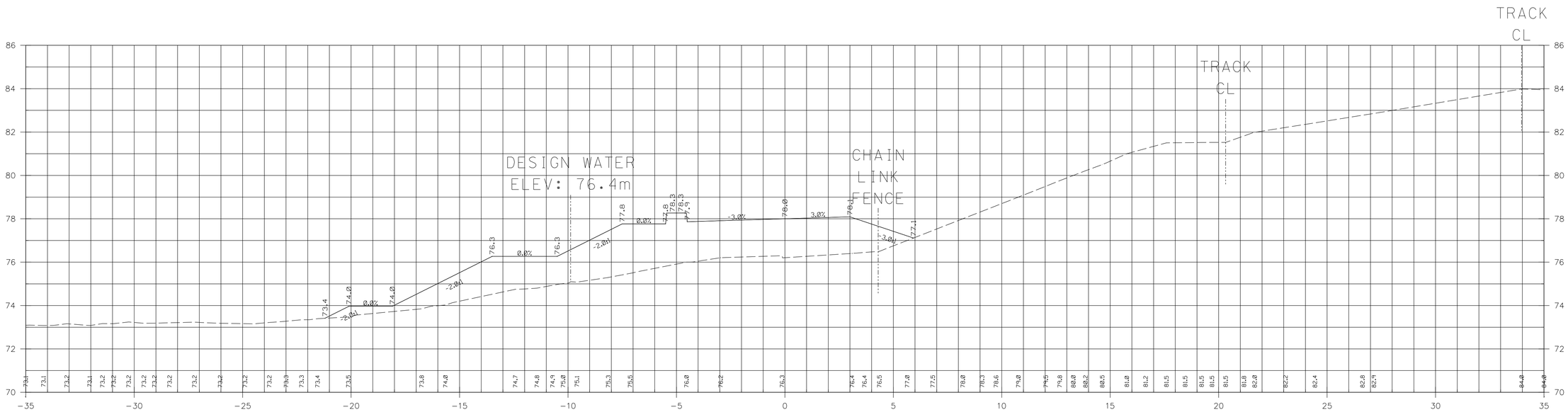

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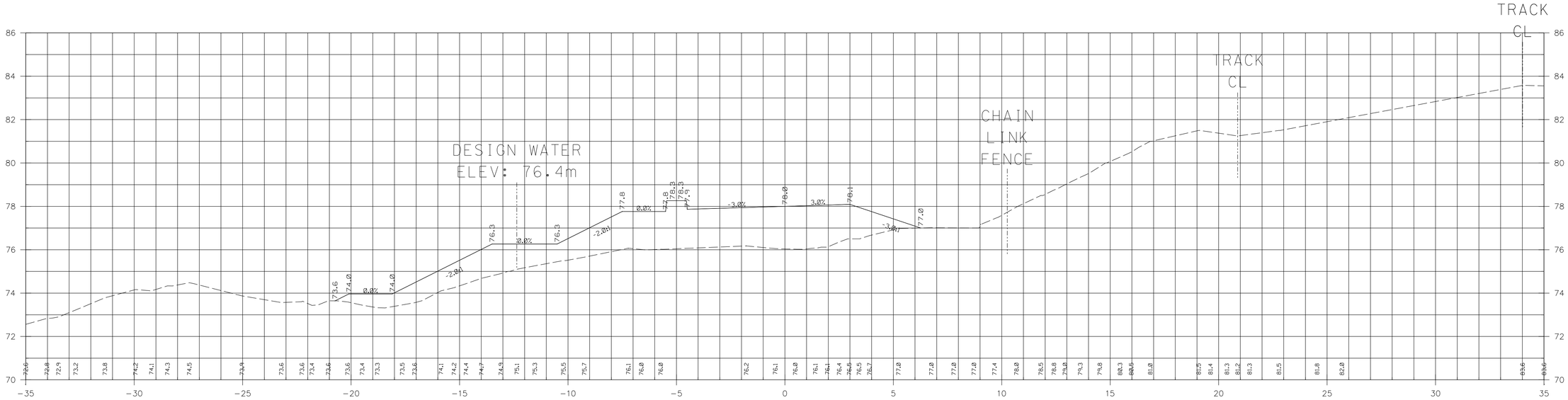
SCALE: 1:100 STA 0+480.00 TO STA 0+500.00



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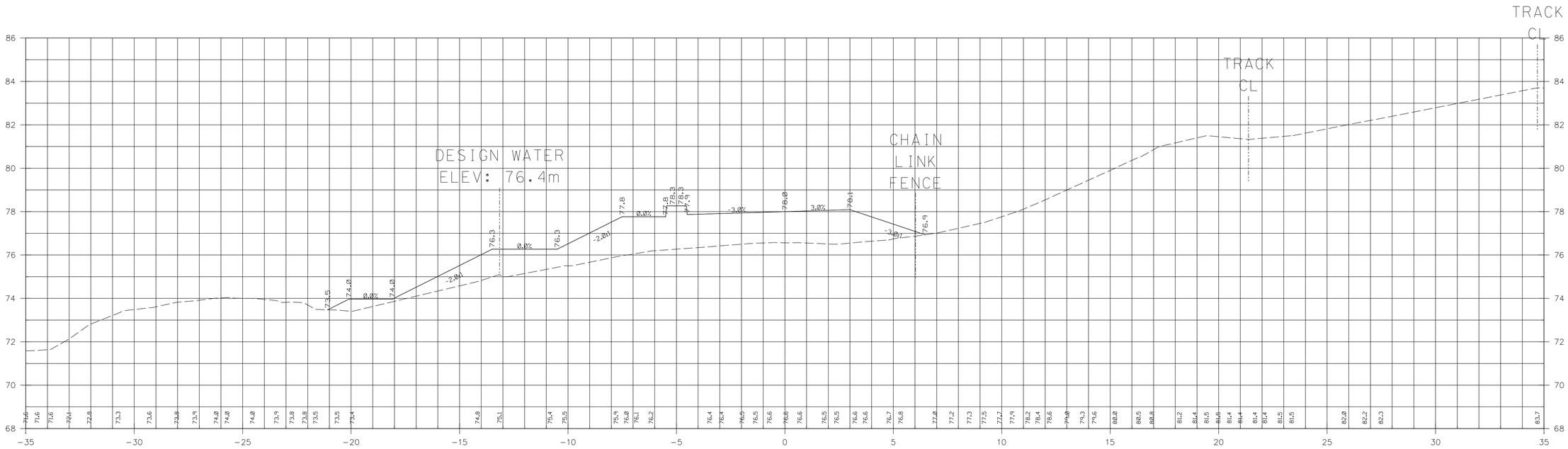
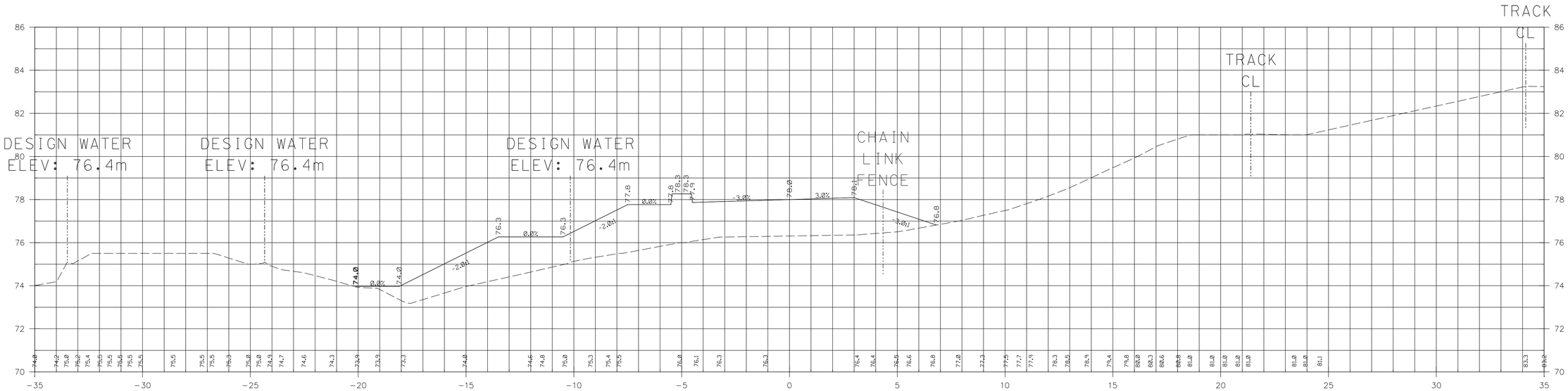


0+480.00

SCALE: 1:100 STA 0+520.00 TO STA 0+540.00



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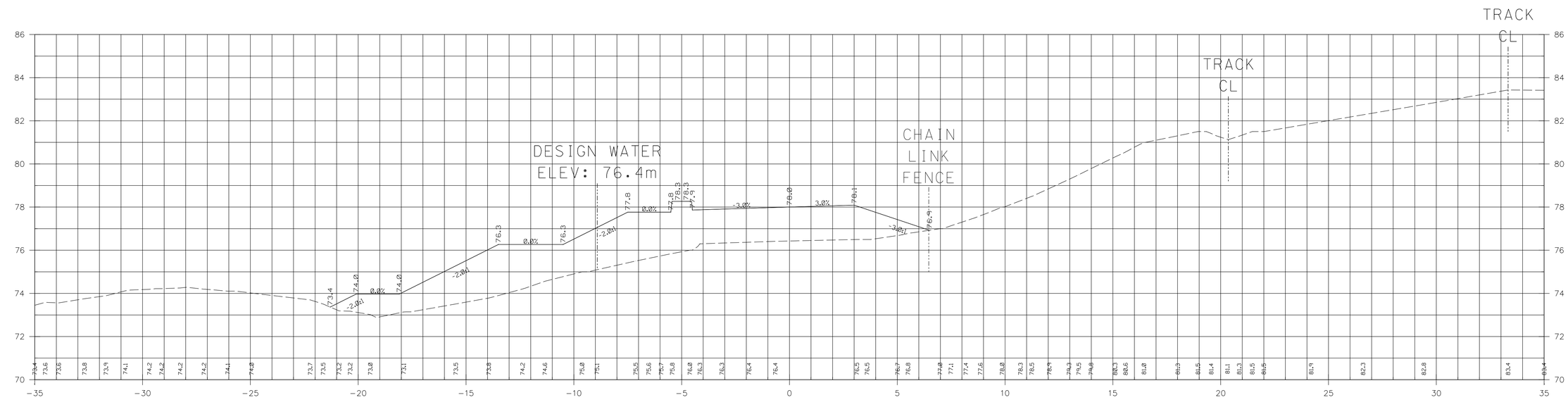

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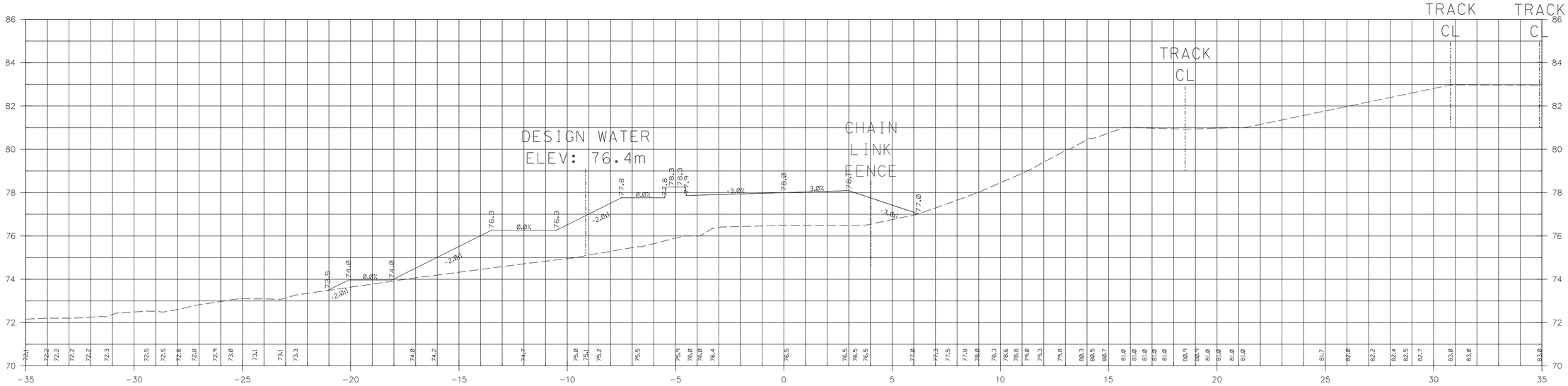
SCALE: 1:100 STA 0+560.00 TO STA 0+580.00



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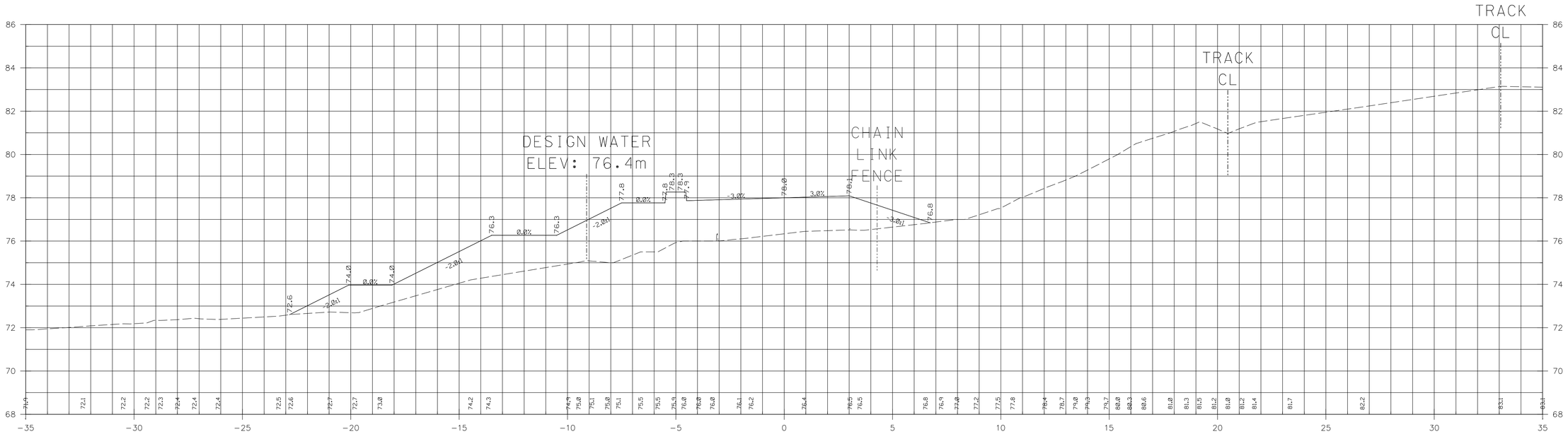

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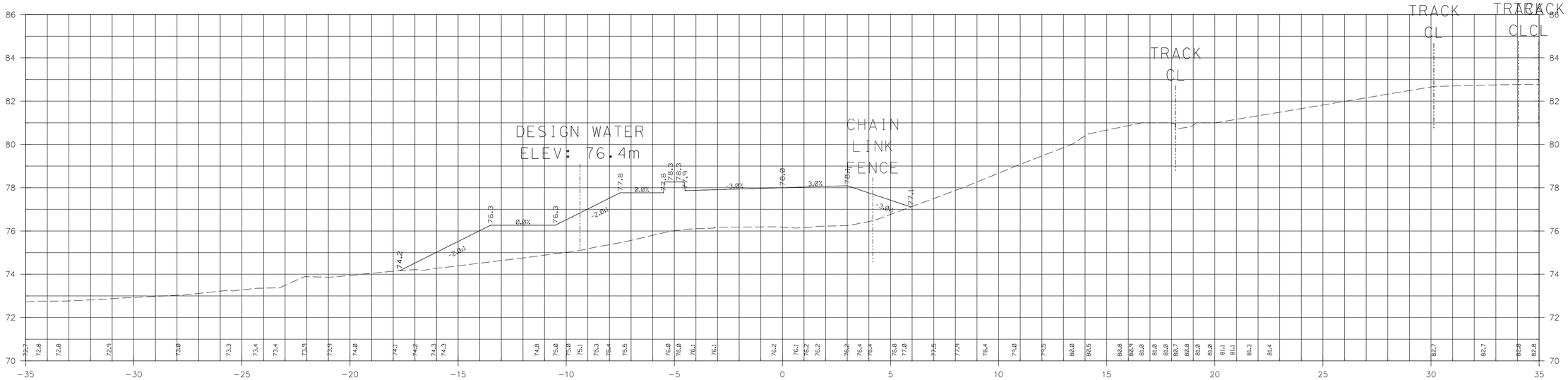
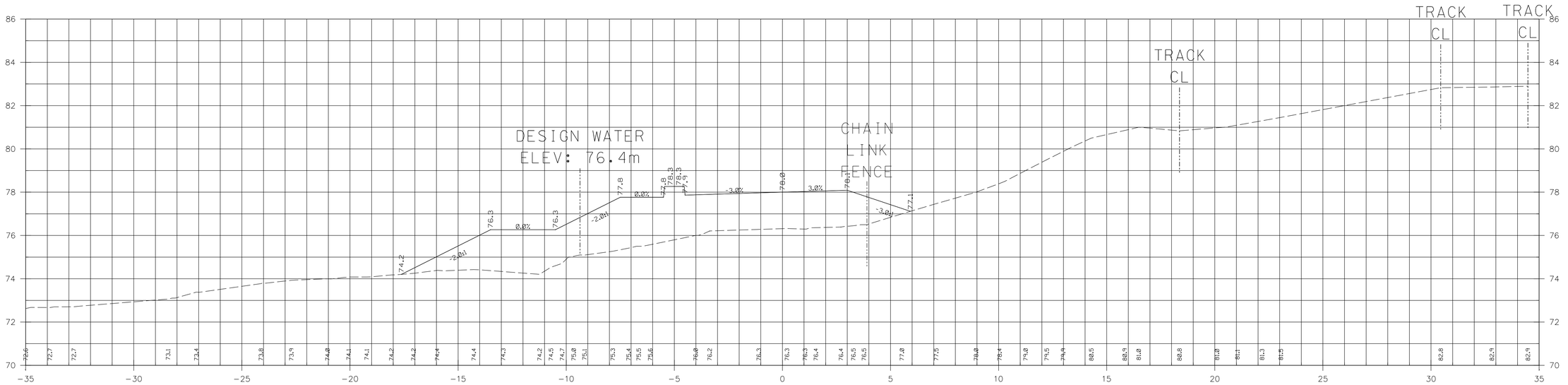
SCALE: 1:100 STA 0+600.00 TO STA 0+620.00

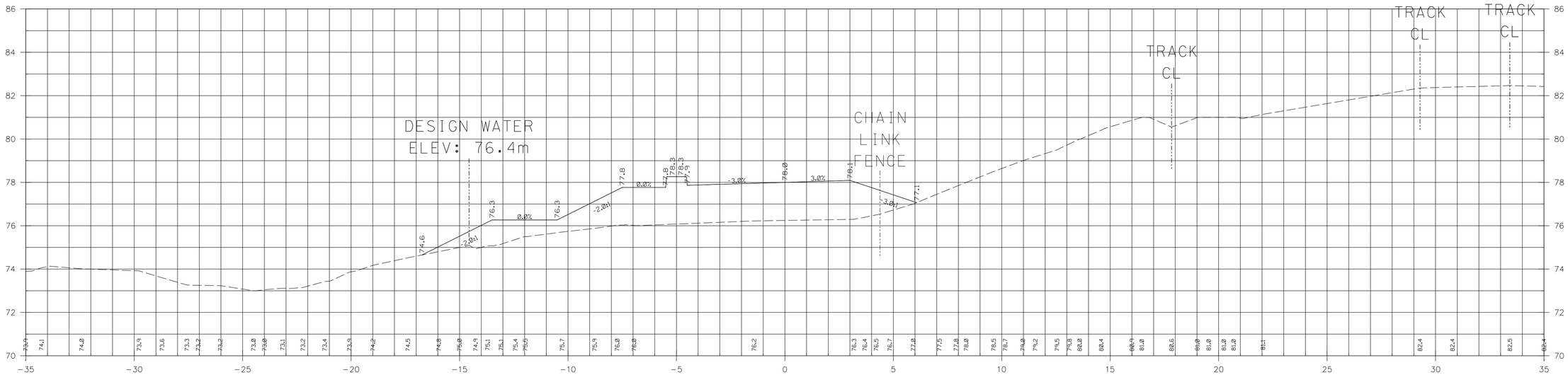


0+620.00



0+600.00

SCALE: 1:100 STA 0+640.00 TO STA 0+660.00



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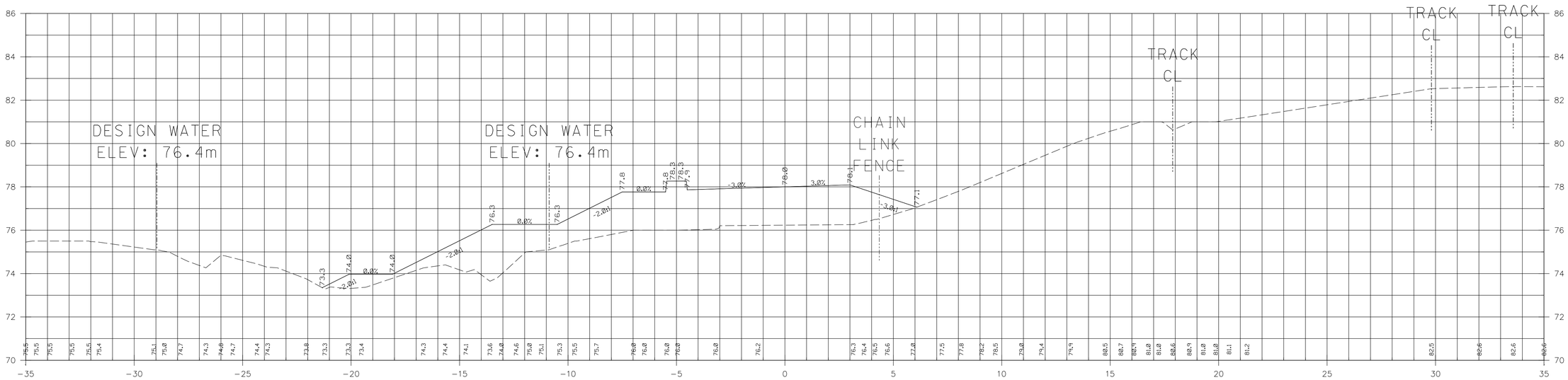
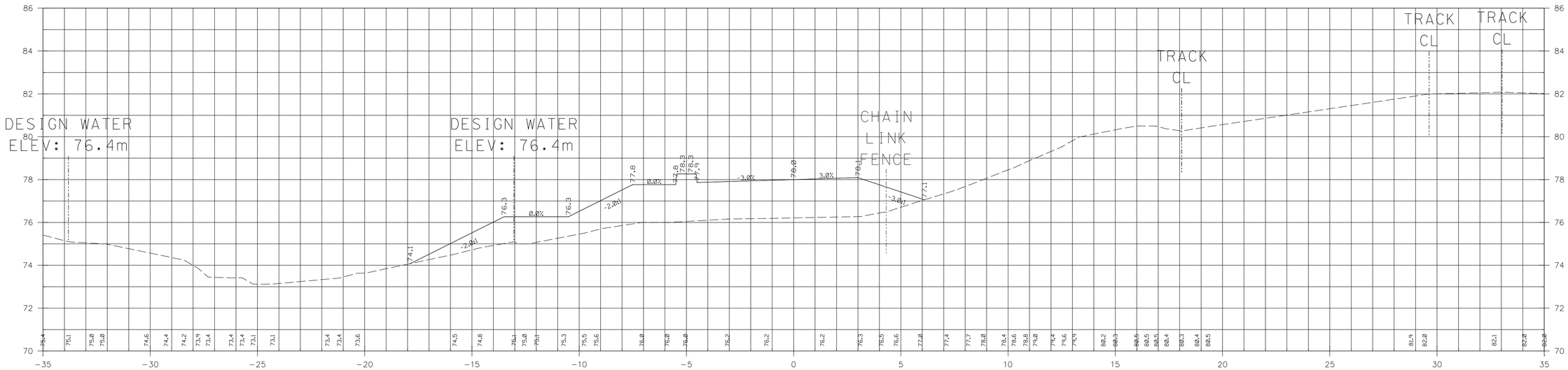


0+640.00

SCALE: 1:100 STA 0+680.00 TO STA 0+700.00



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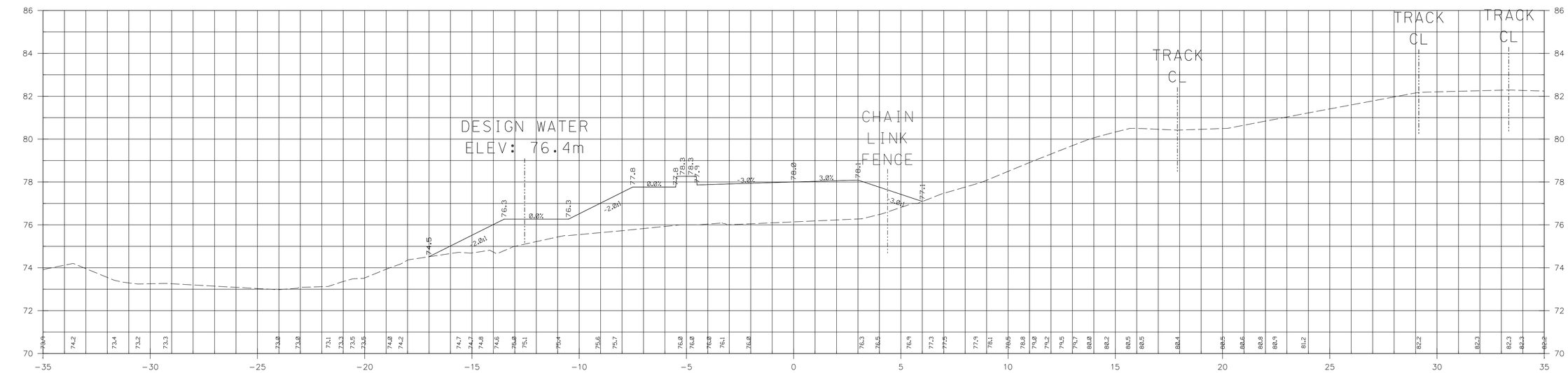

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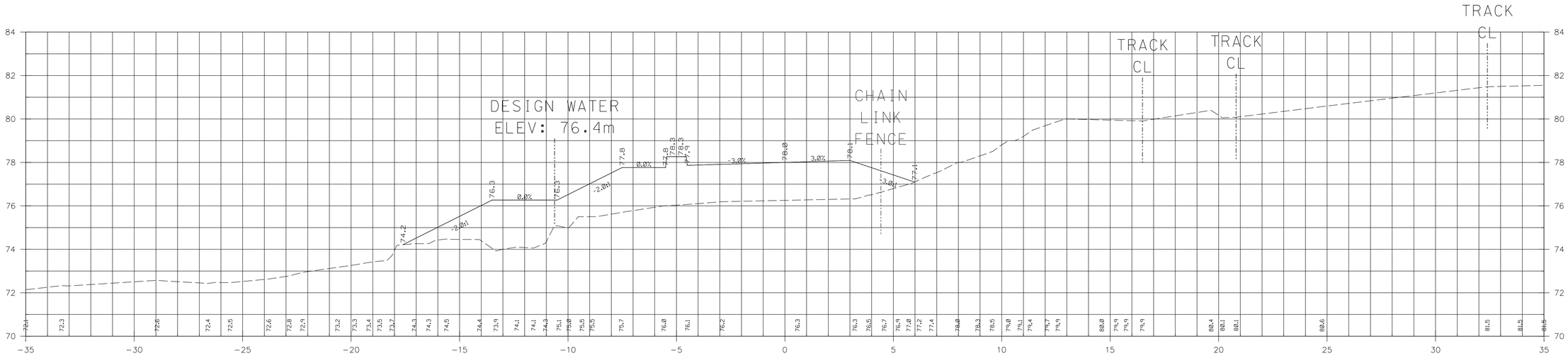
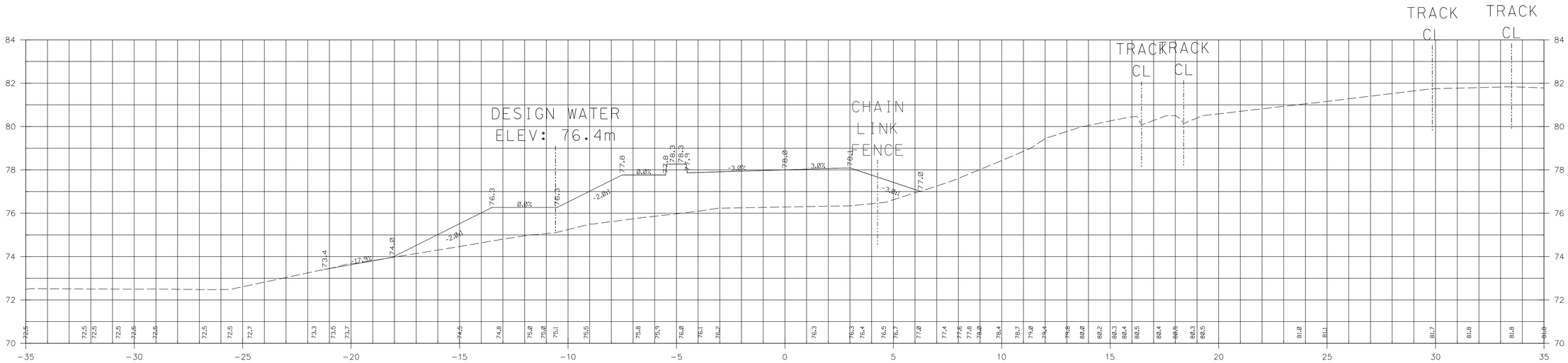
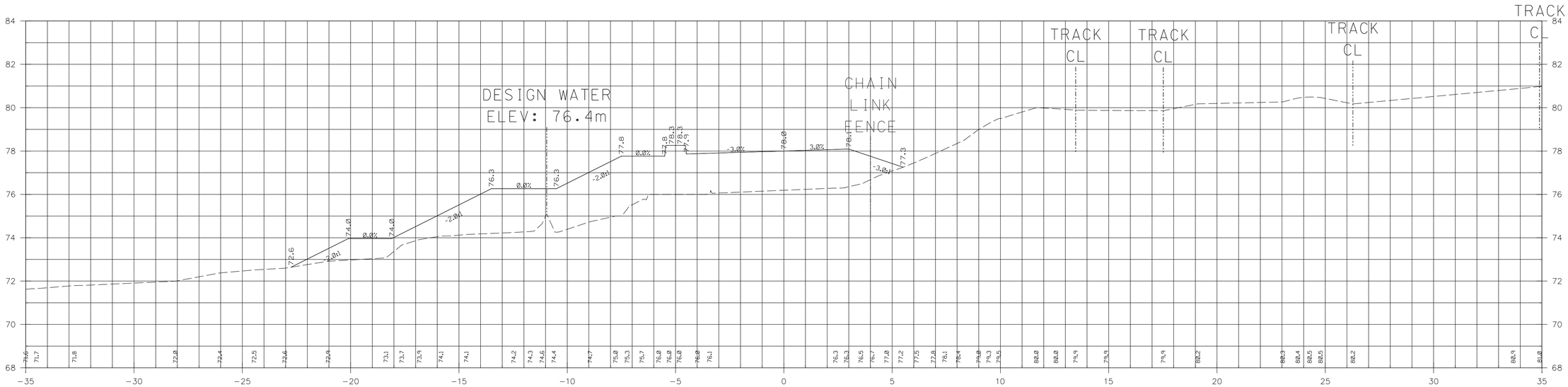
SCALE: 1:100 STA 0+720.00 TO STA 0+740.00





SCALE: 1:100 STA 0+760.00 TO STA 0+780.00



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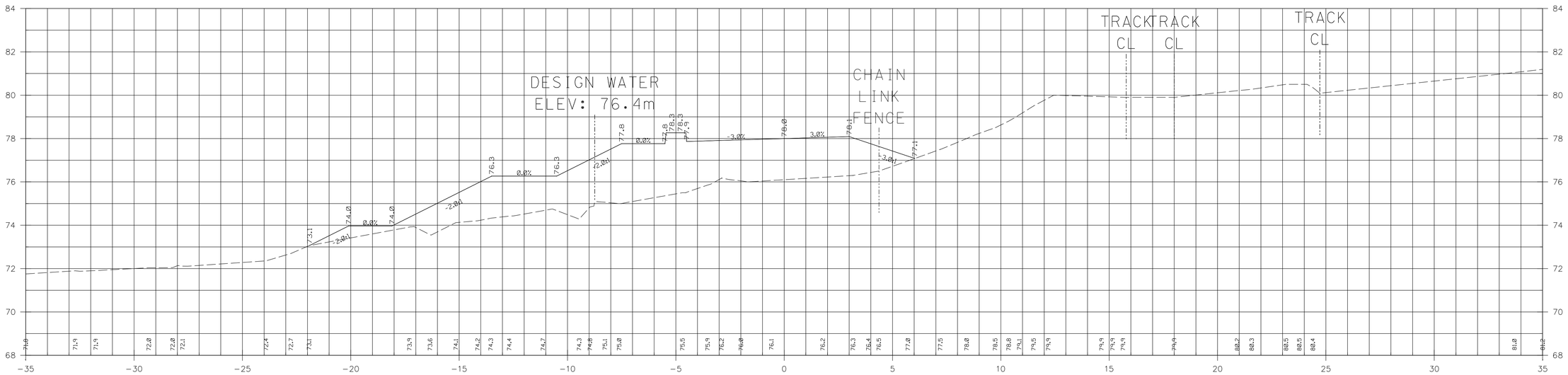
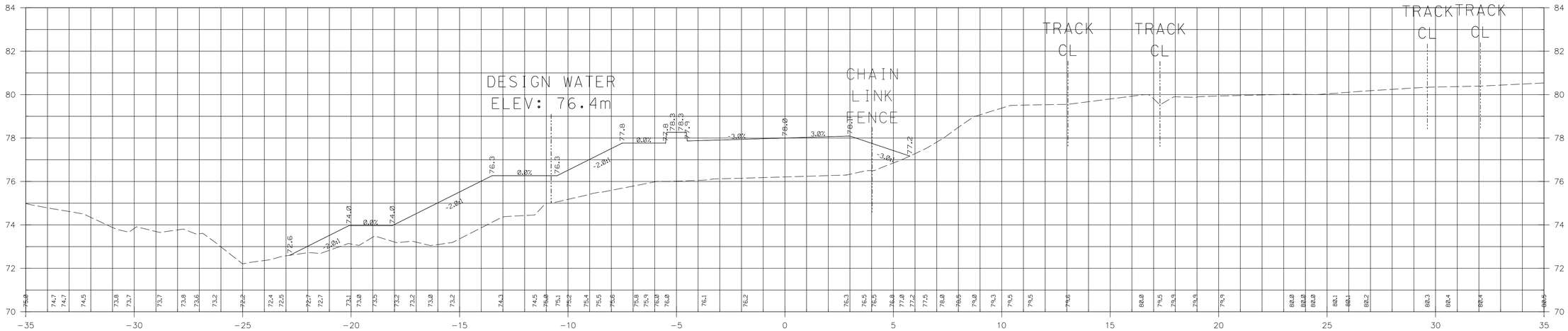
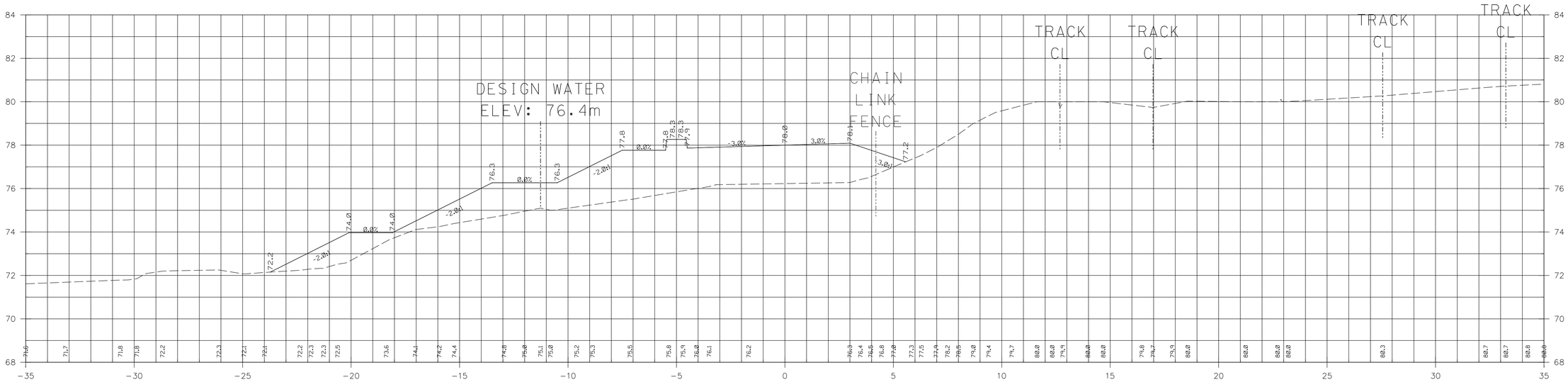


0+760.00

SCALE: 1:100 STA 0+800.00 TO STA 0+820.00

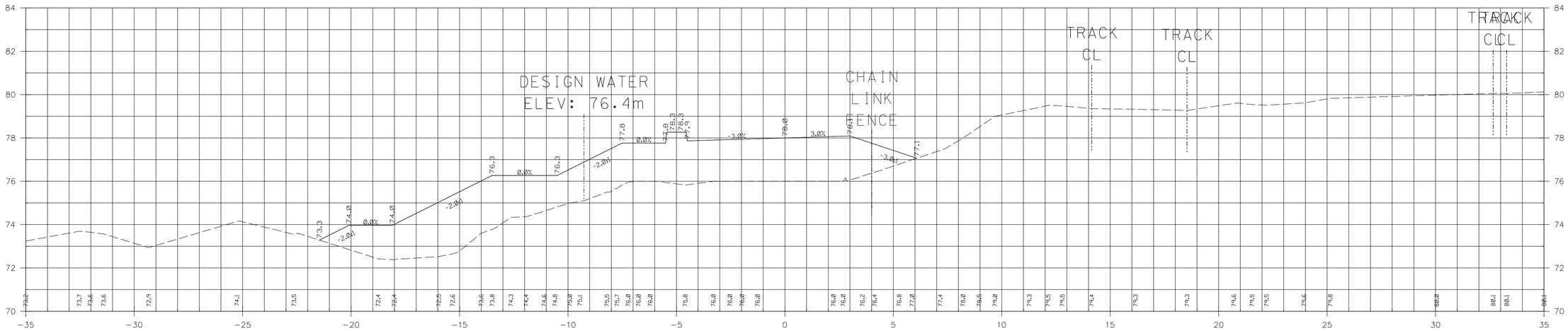


0+820.00



0+800.00

SCALE: 1:100 STA 0+840.00 TO STA 0+860.00



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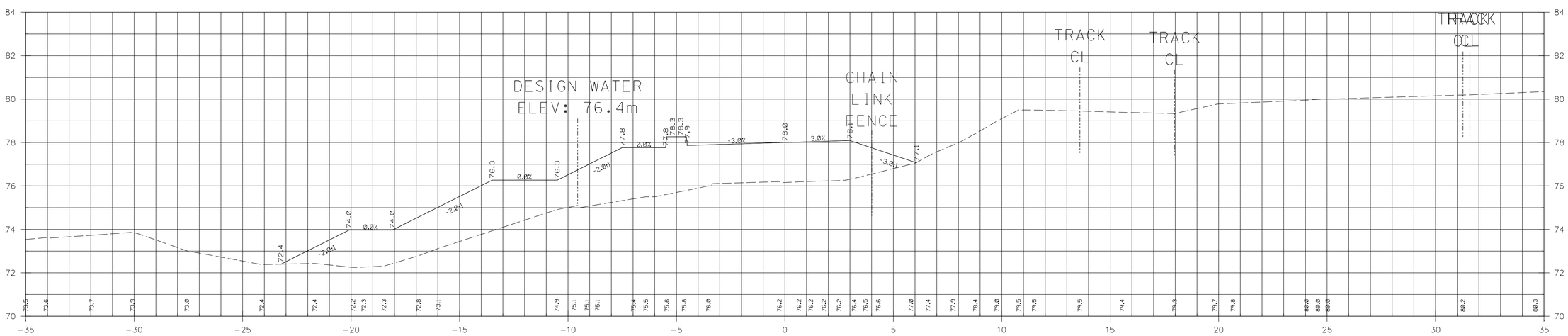
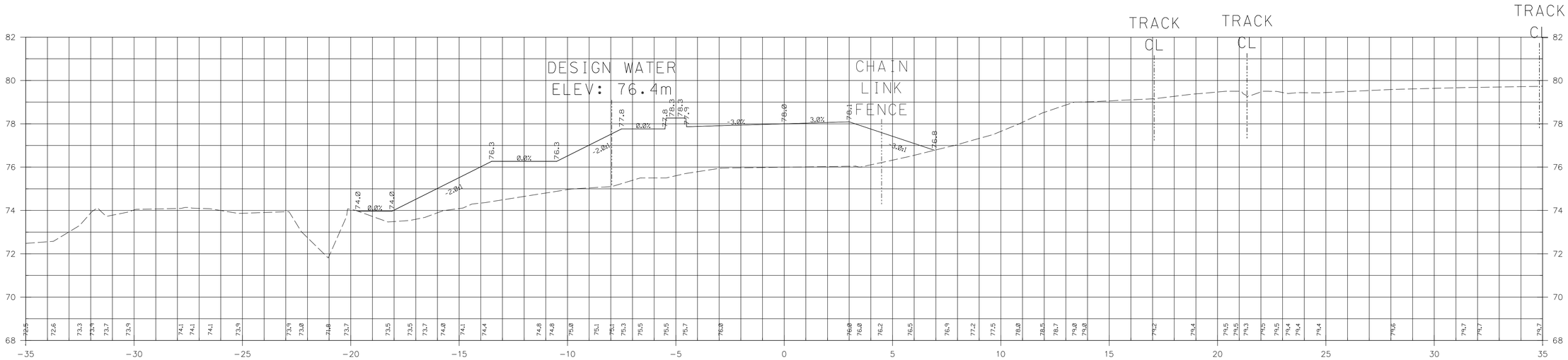
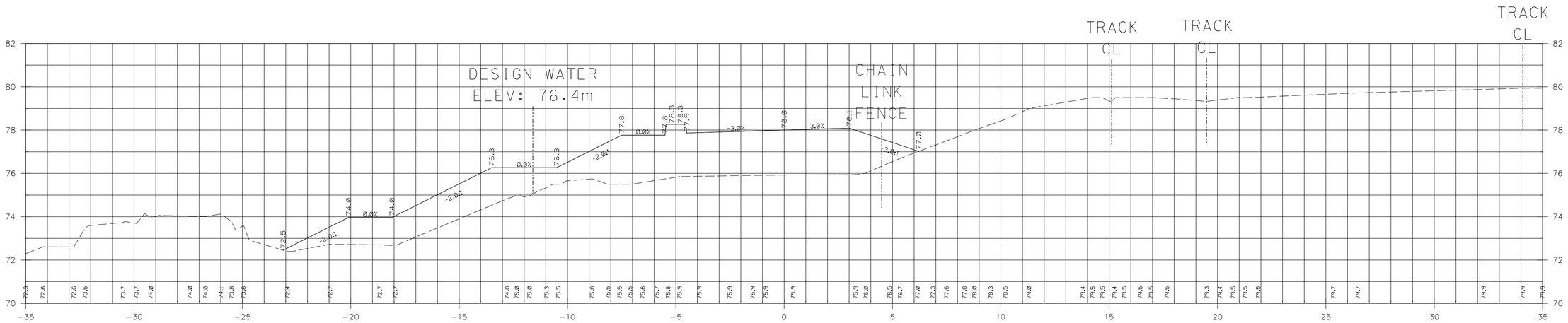


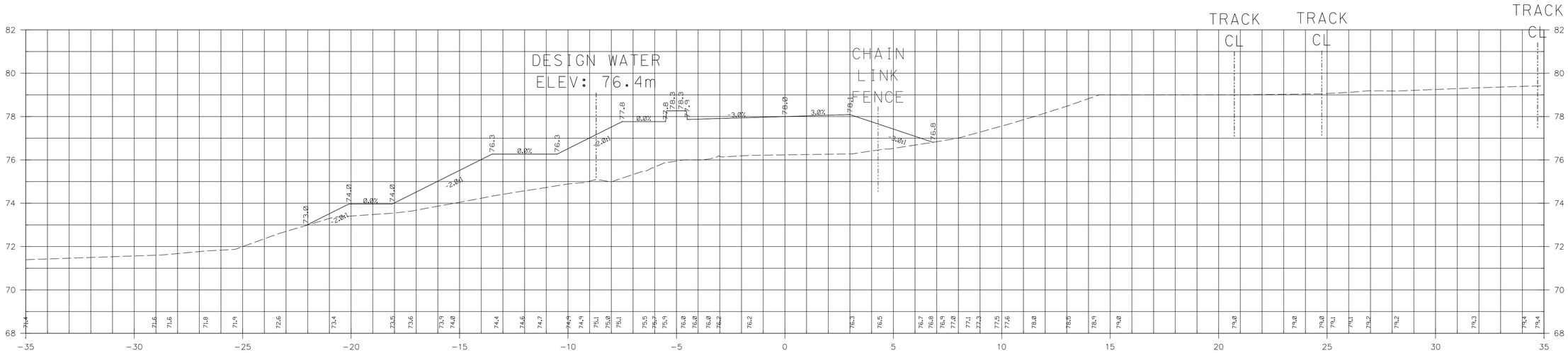
0+840.00

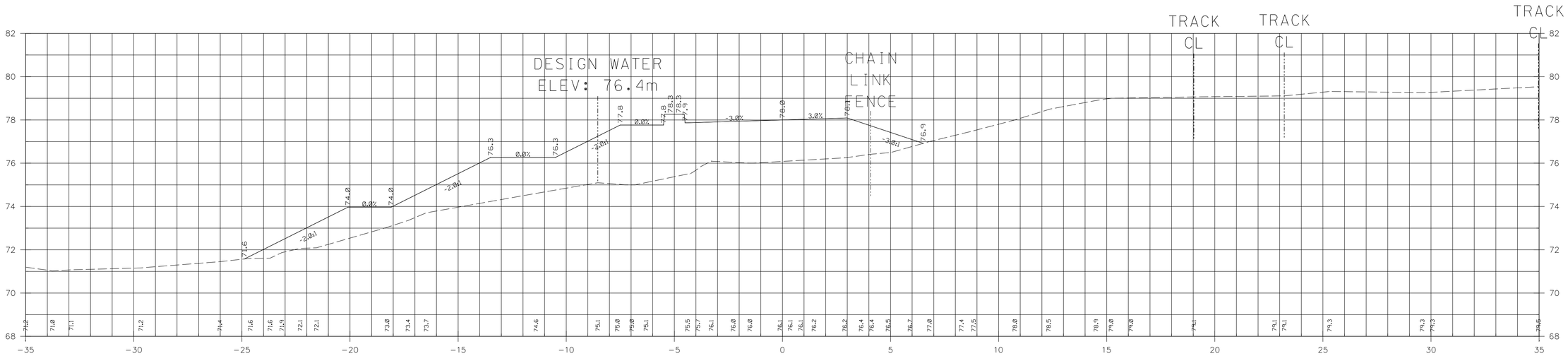
SCALE: 1:100 STA 0+880.00 TO STA 0+900.00



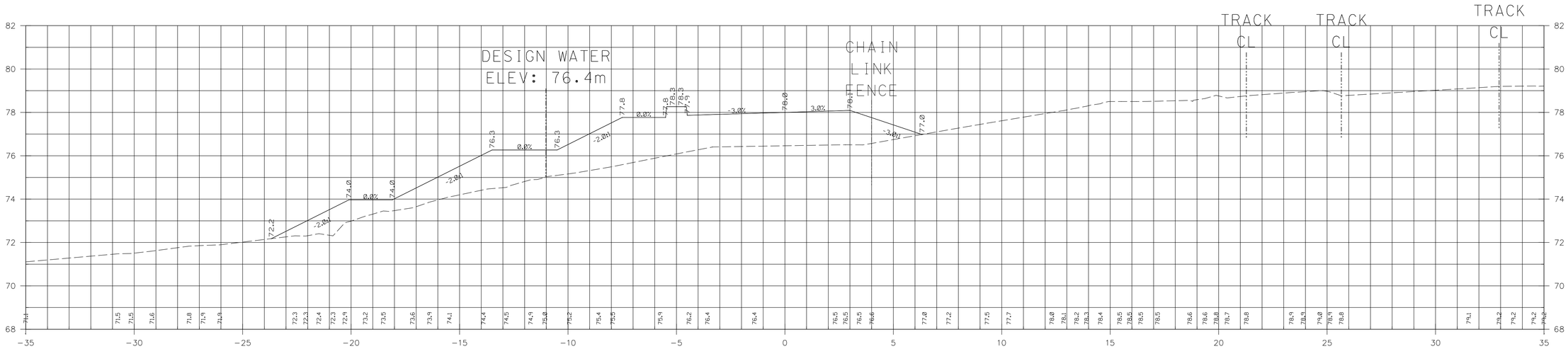


SCALE: 1:100 STA 0+920.00 TO STA 0+940.00

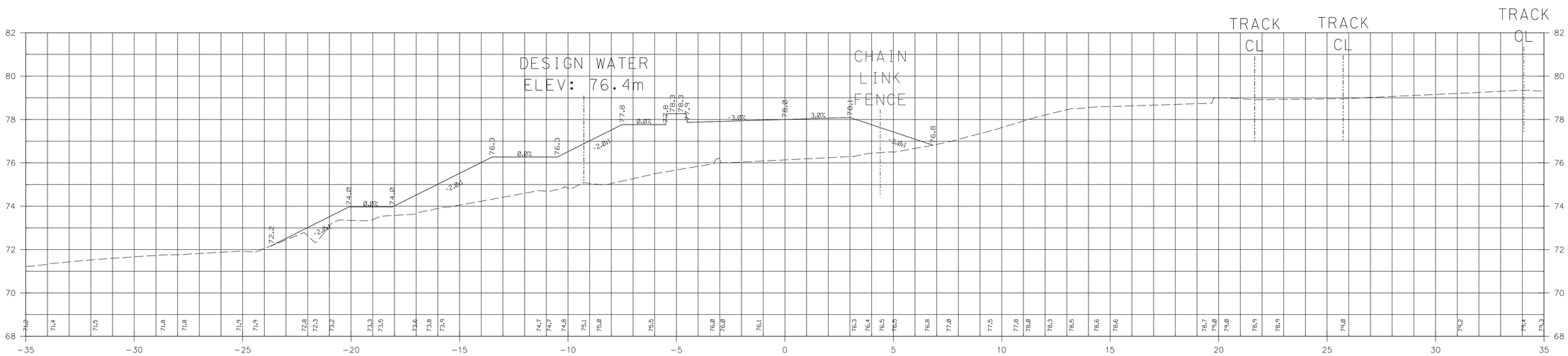




SCALE: 1:100 STA 0+960.00 TO STA 0+980.00

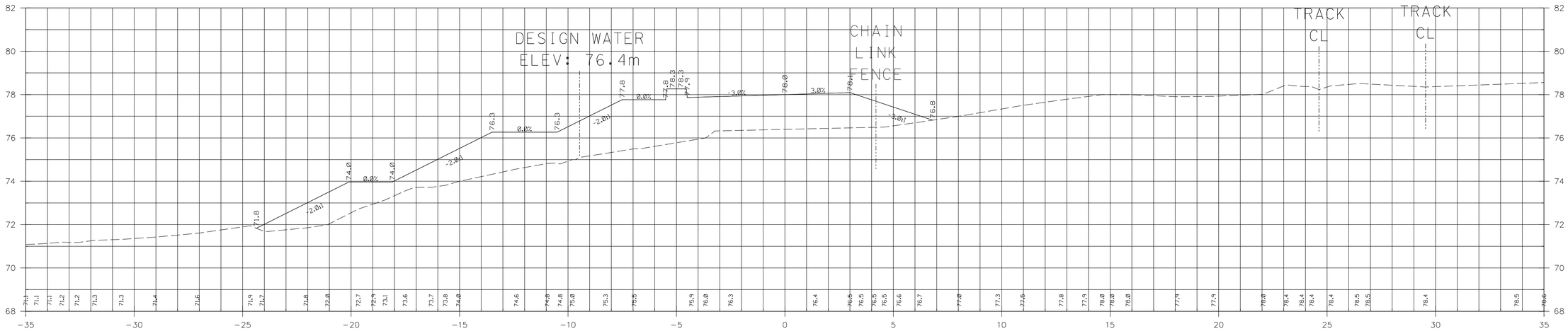


0+980.00

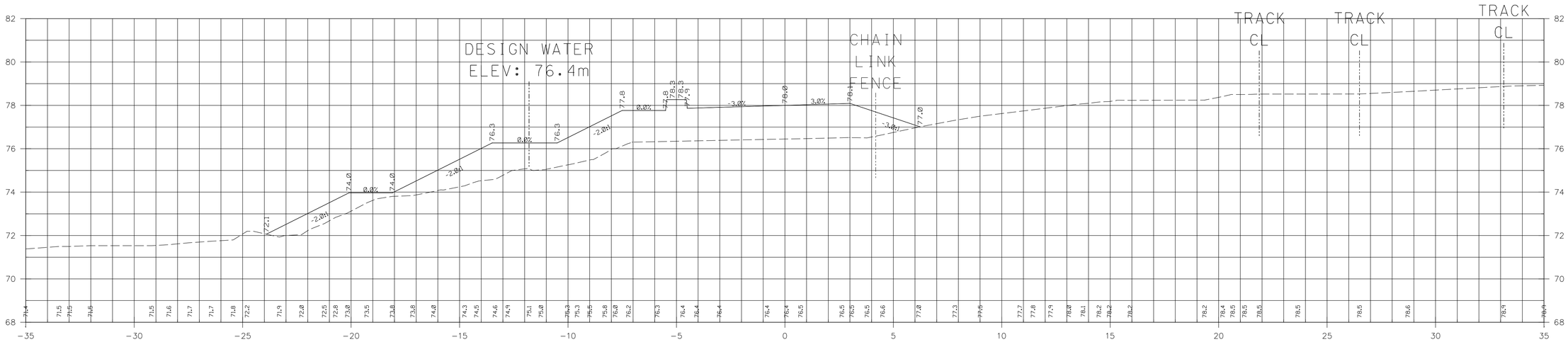


0+960.00

SCALE: 1:100 STA 1+000.00 TO STA 1+020.00

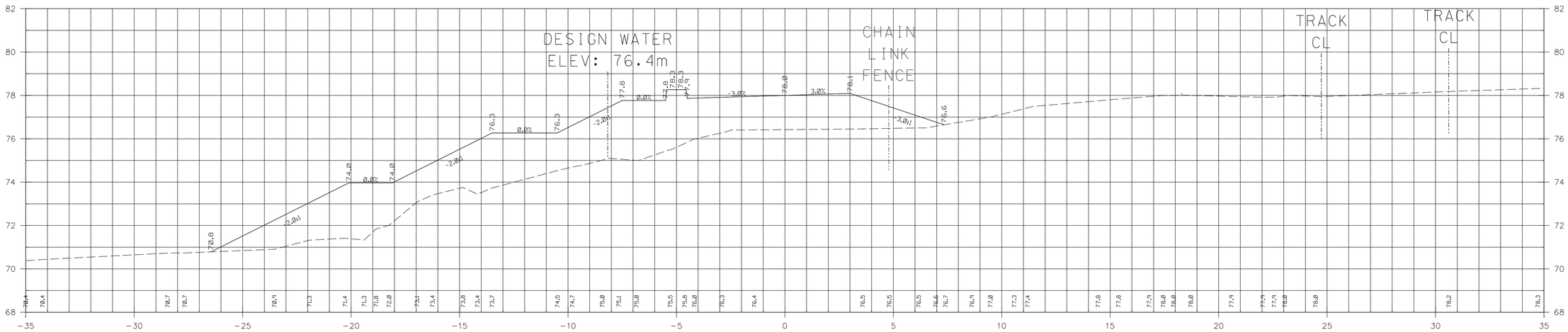


1+020.00

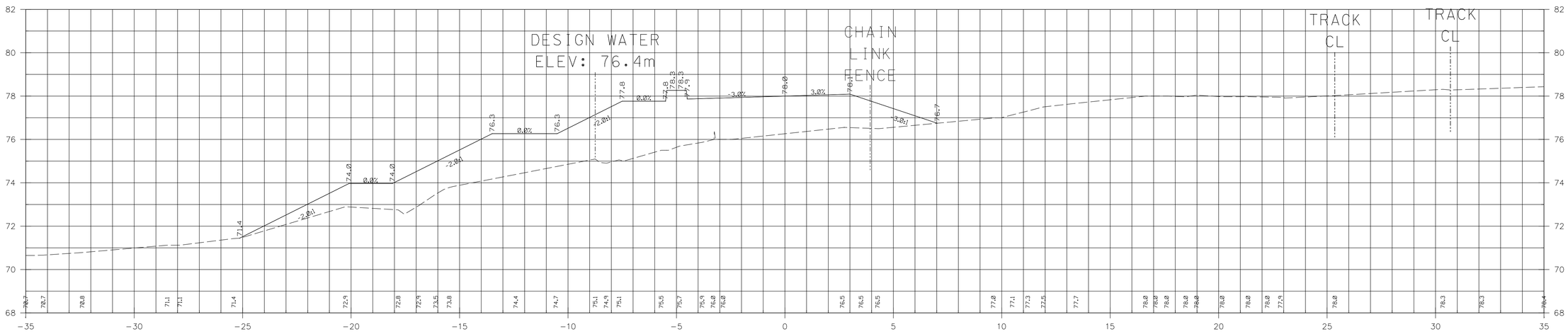


1+000.00

SCALE: 1:100 STA 1+040.00 TO STA 1+060.00



1+060.00



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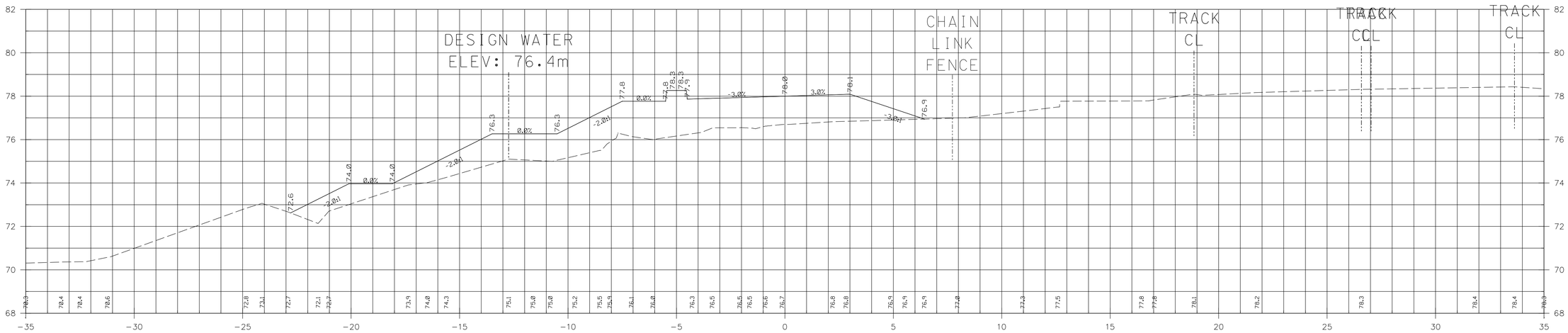
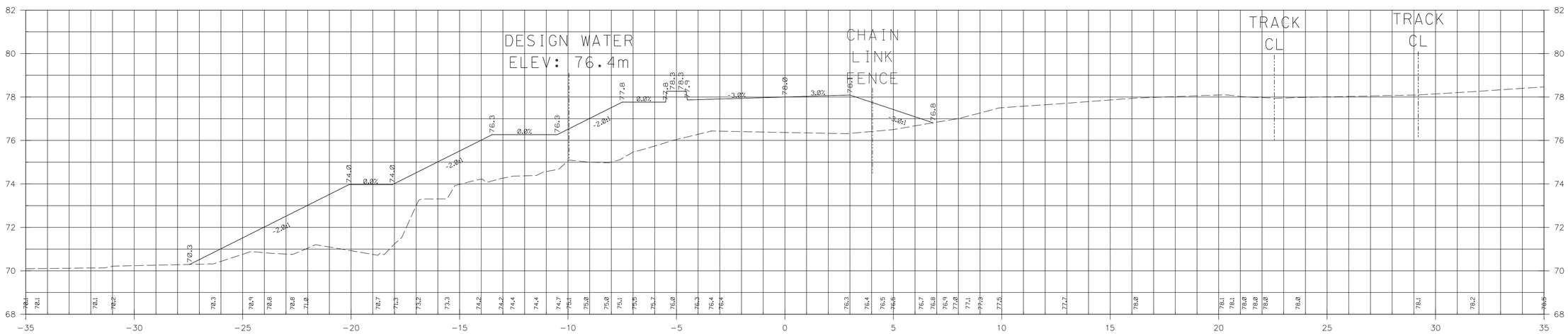
SCALE: 1:100 STA 1+080.00 TO STA 1+100.00

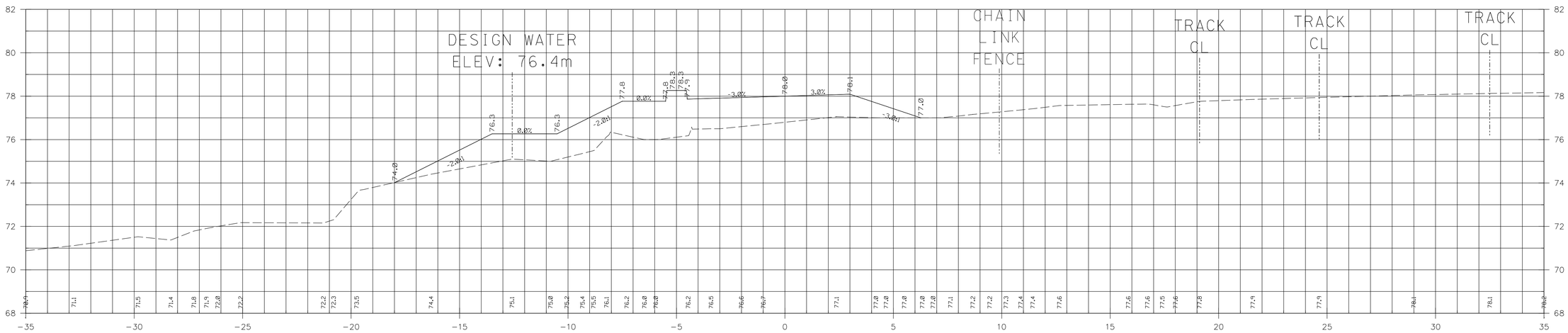


1+100.00

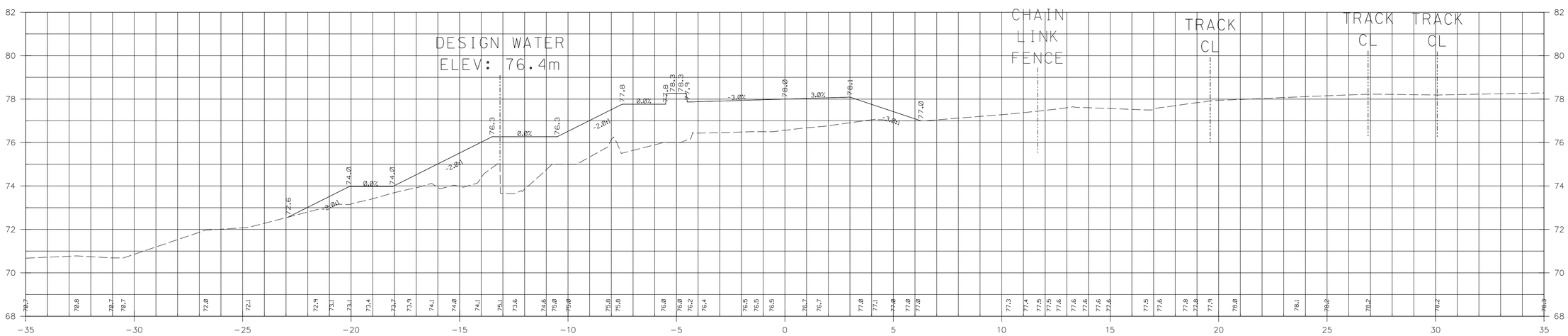


1+080.00

SCALE: 1:100 STA 1+120.00 TO STA 1+140.00

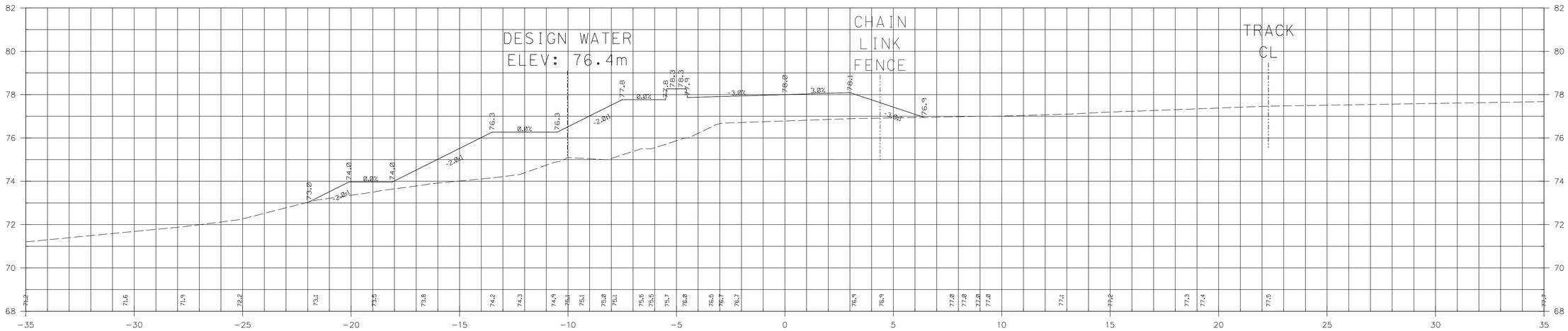


1+140.00

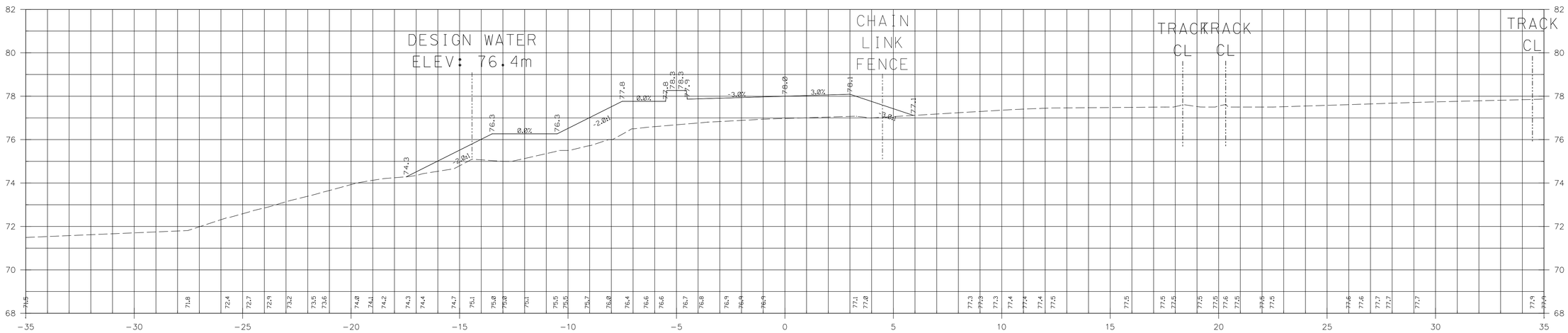


1+120.00

SCALE: 1:100 STA 1+160.00 TO STA 1+180.00

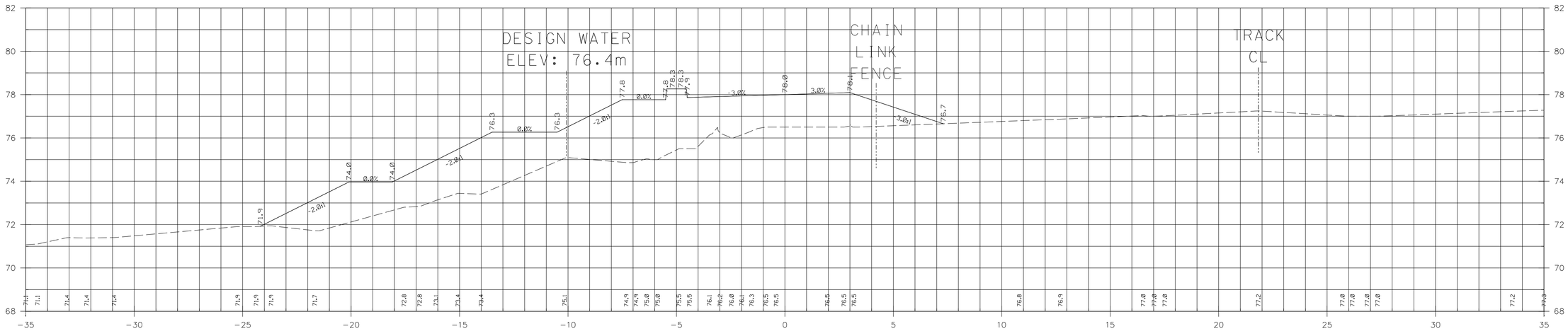


1+180.00

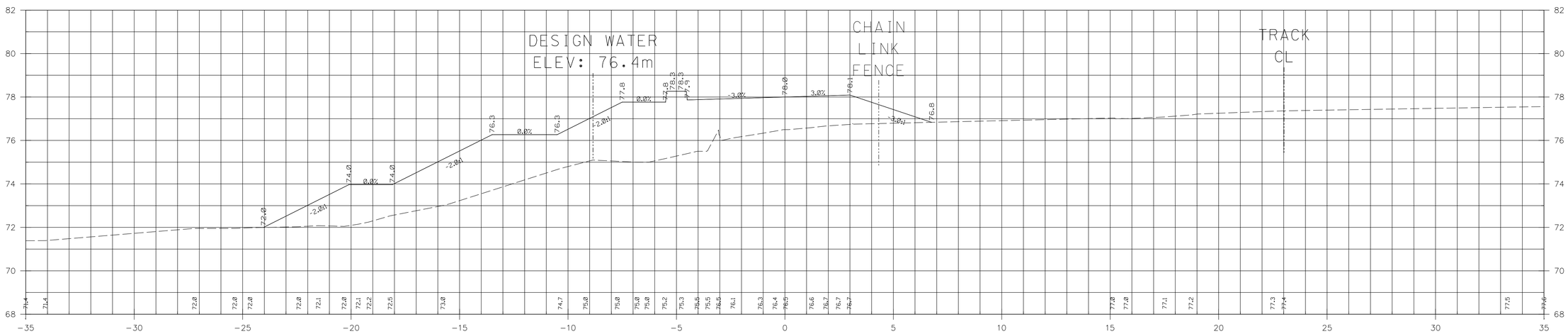


1+160.00

SCALE: 1:100 STA 1+200.00 TO STA 1+220.00

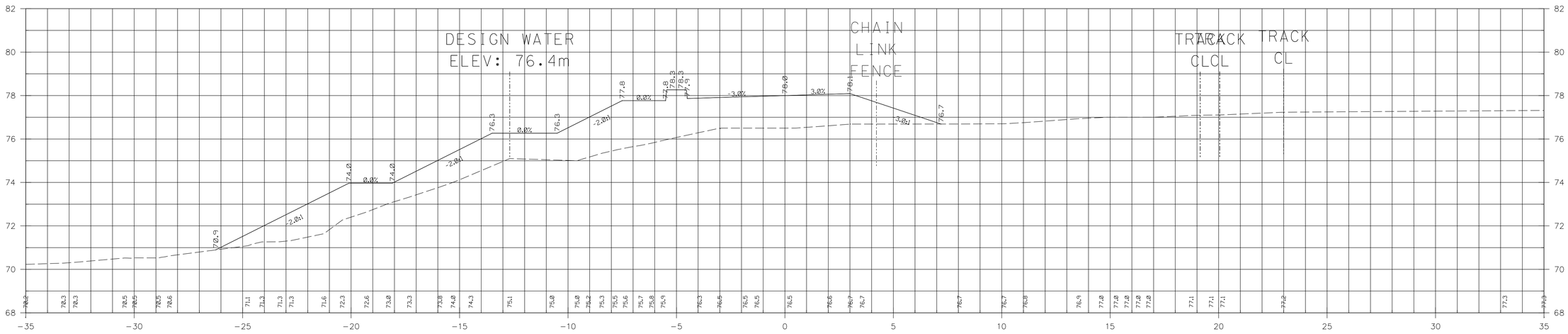


1+220.00

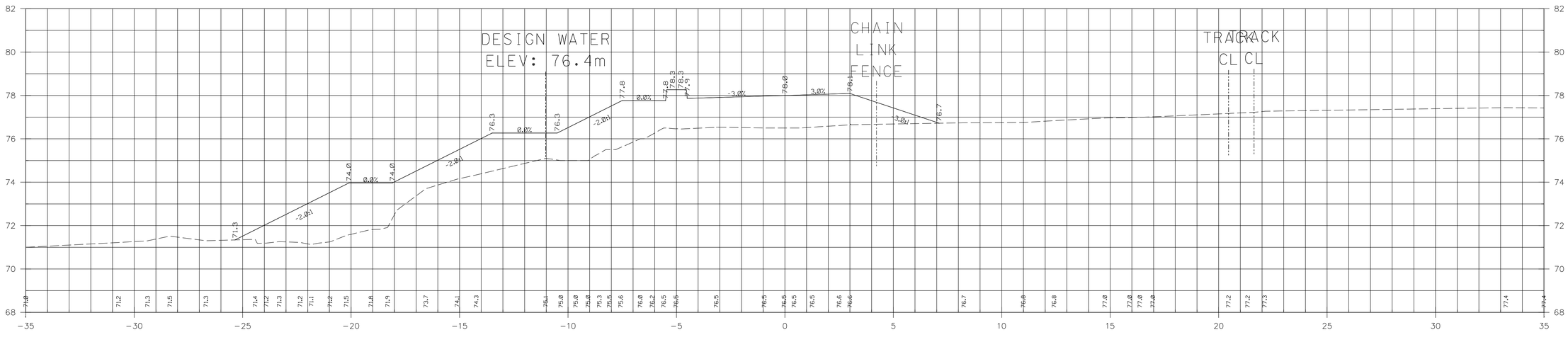


1+200.00

SCALE: 1:100 STA 1+240.00 TO STA 1+260.00

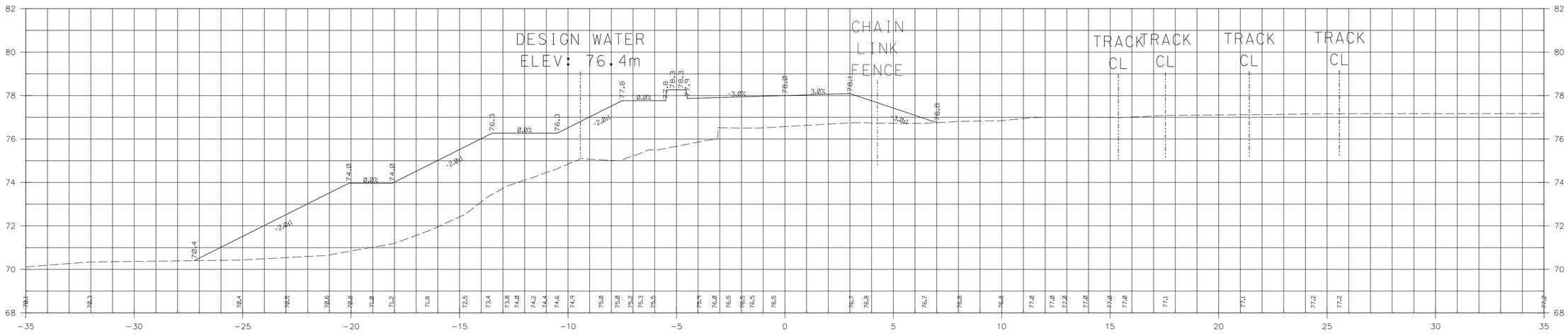


1+260.00

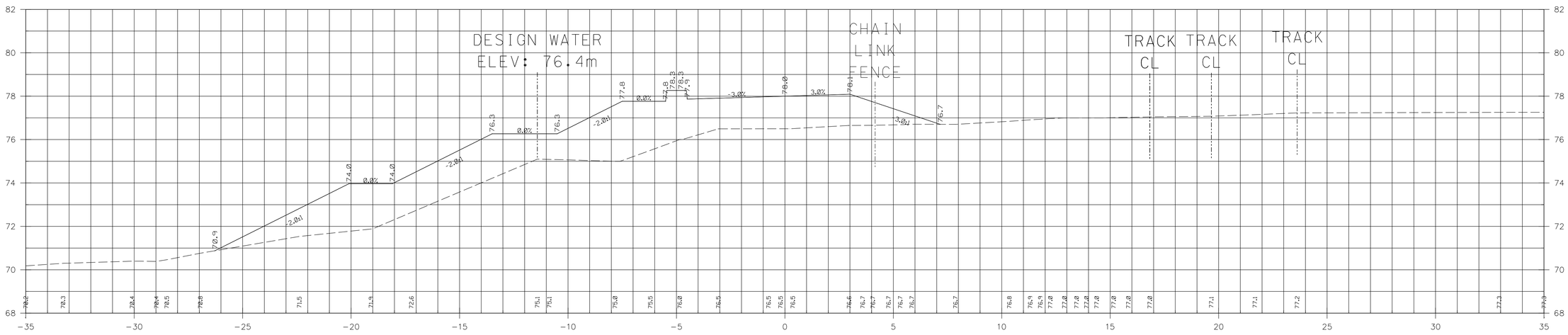


1+240.00

SCALE: 1:100 STA 1+280.00 TO STA 1+300.00

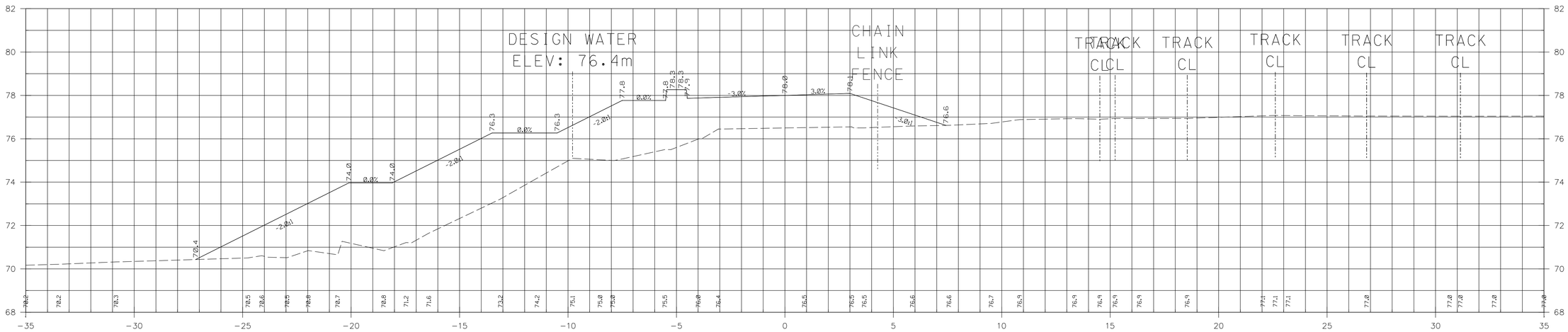


1+300.00



1+280.00

SCALE: 1:100 STA 1+320.00 TO STA 1+340.00



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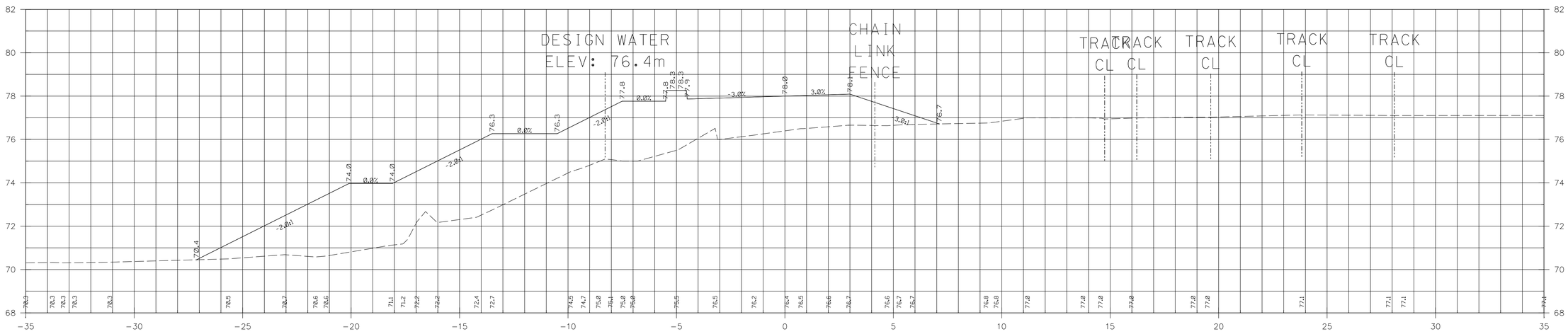
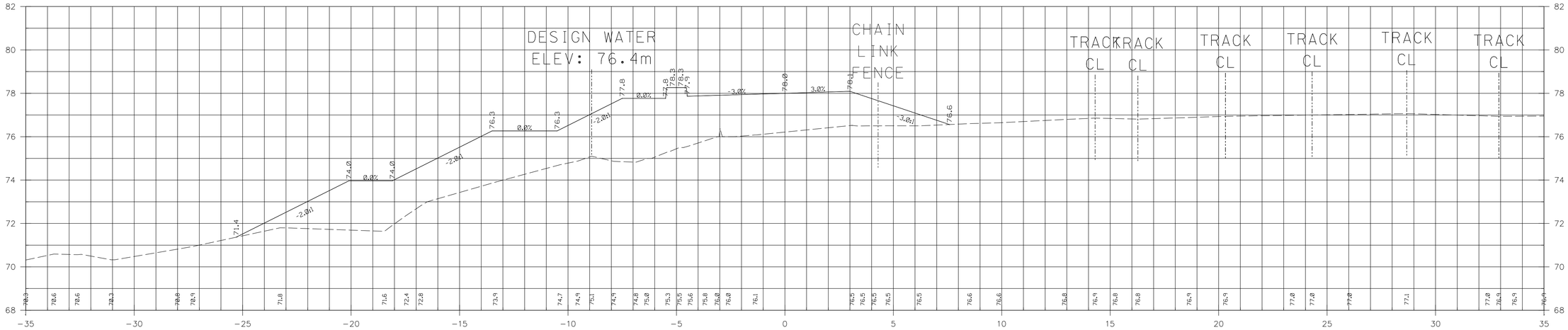
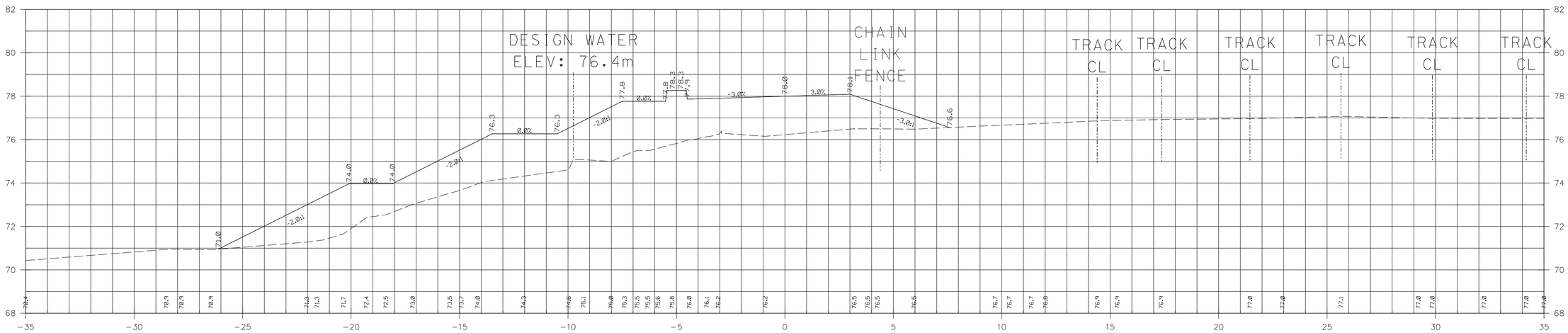


1+320.00

SCALE: 1:100 STA 1+360.00 TO STA 1+380.00

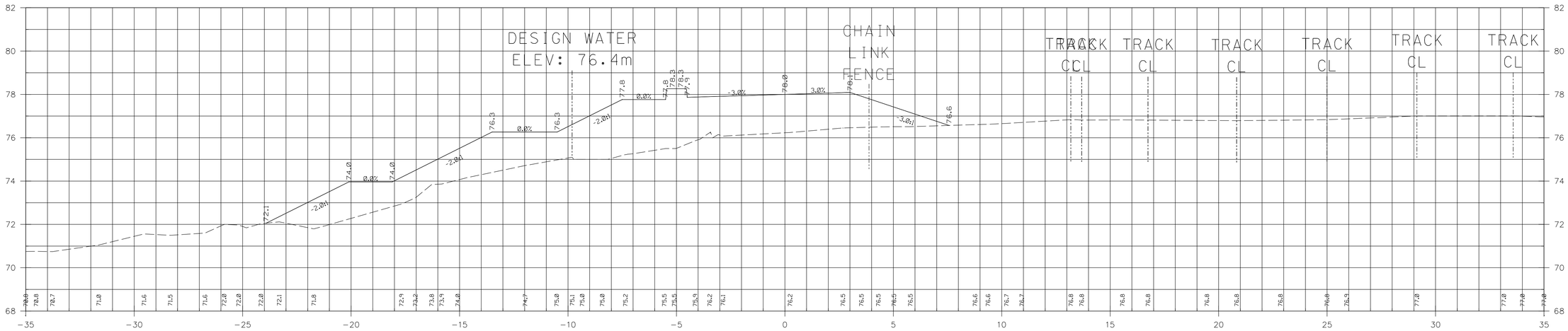


1+380.00

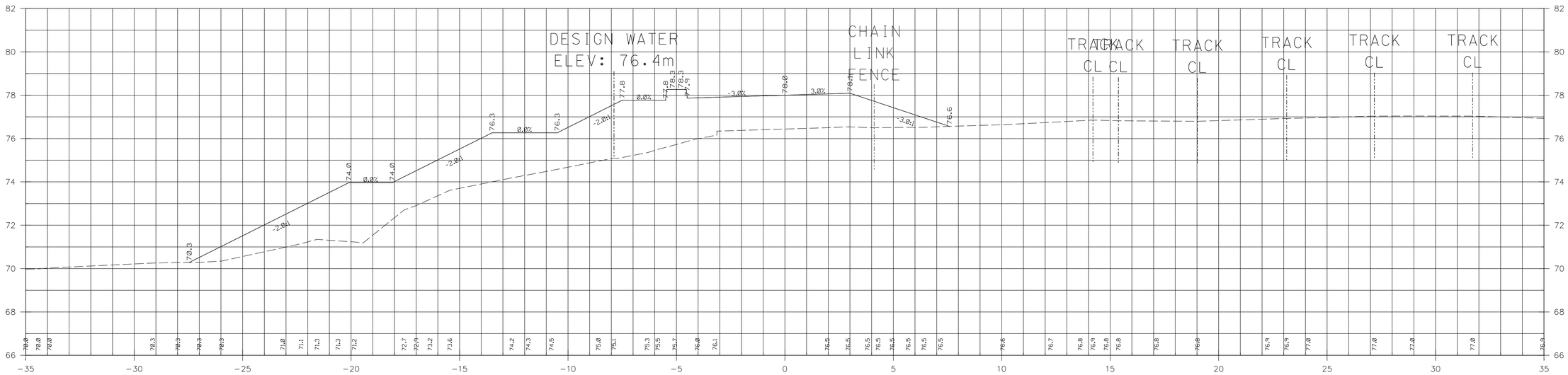


1+360.00

SCALE: 1:100 STA 1+400.00 TO STA 1+420.00

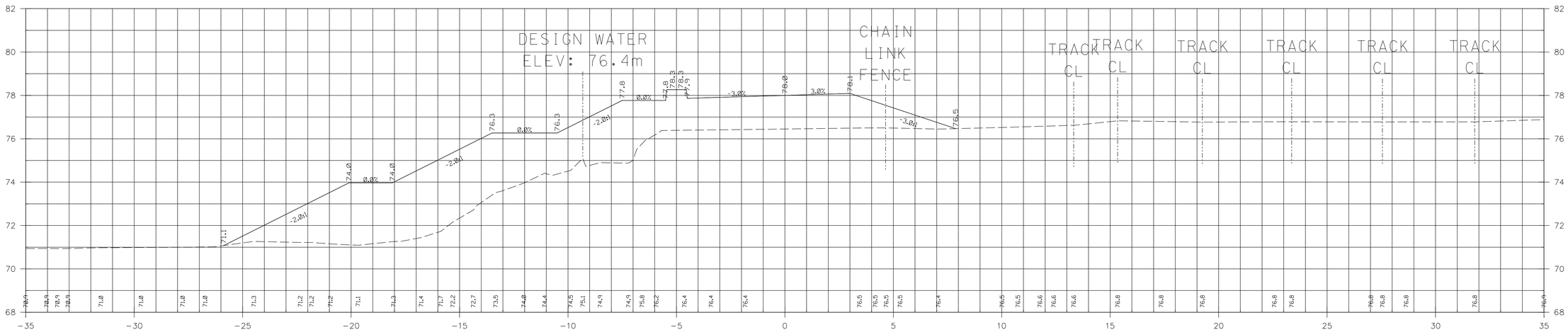


1+420.00

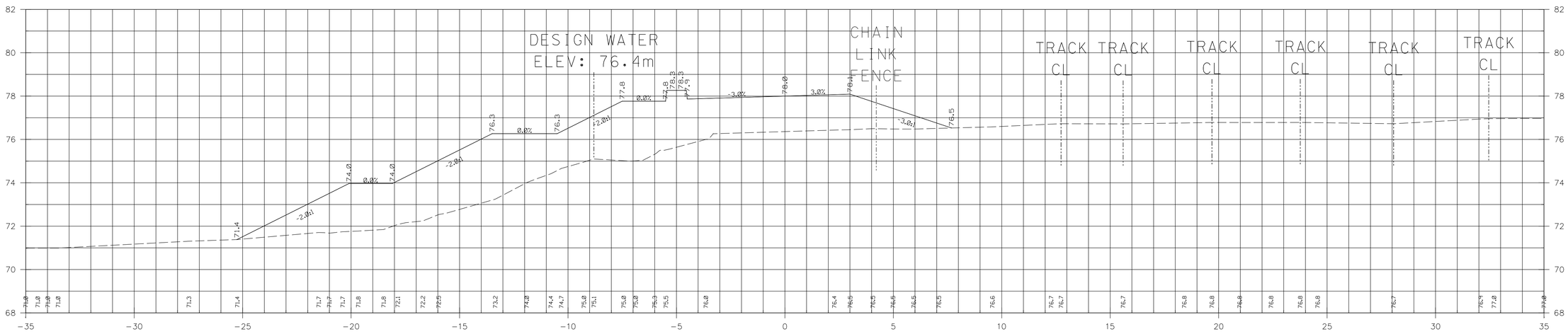


1+400.00

SCALE: 1:100 STA 1+440.00 TO STA 1+460.00

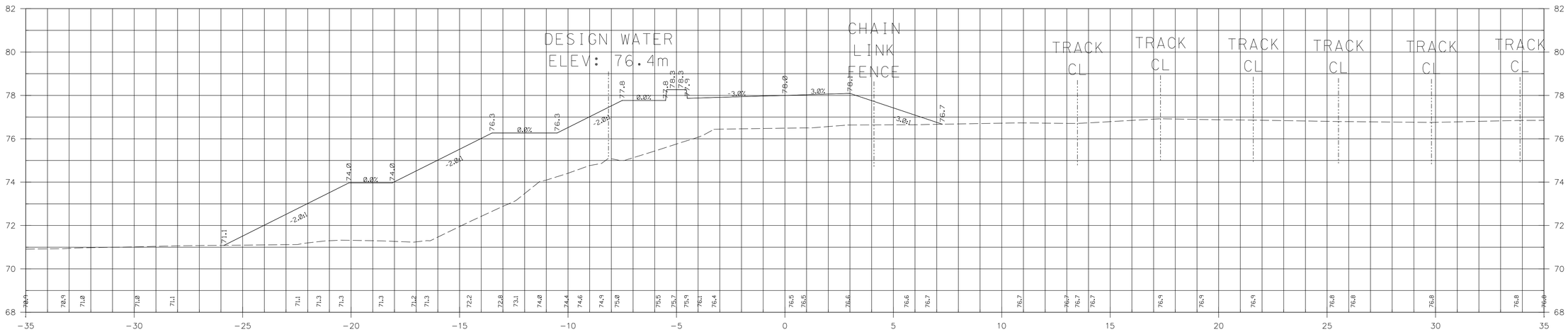


1+460.00

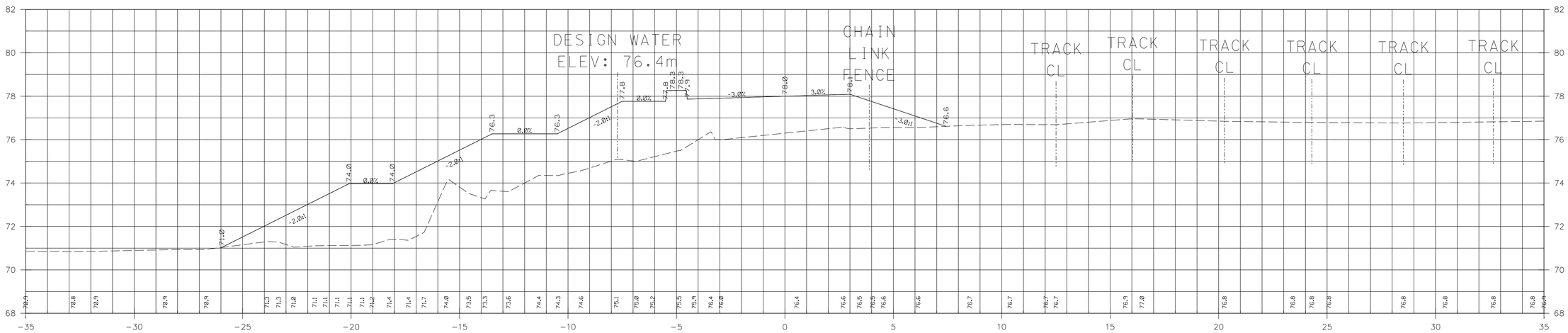


1+440.00

SCALE: 1:100 STA 1+480.00 TO STA 1+500.00

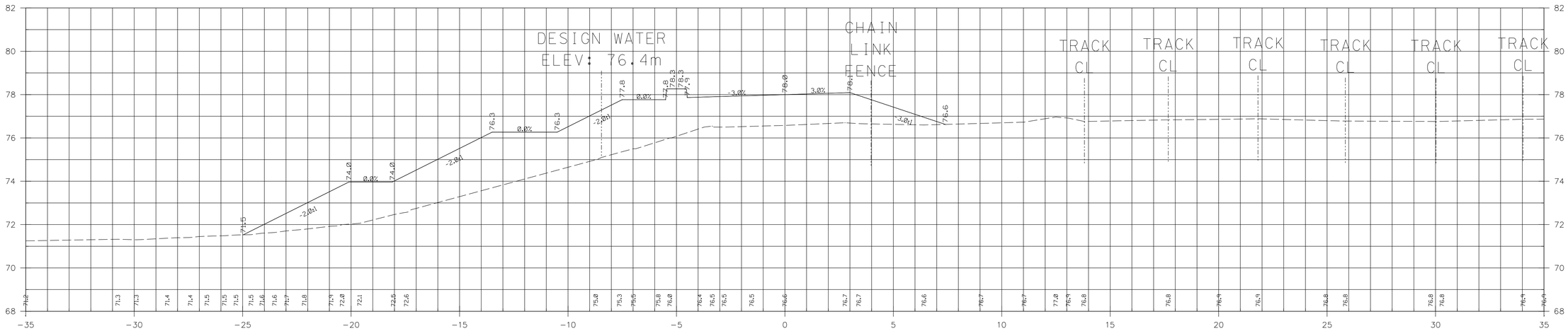


1+500.00

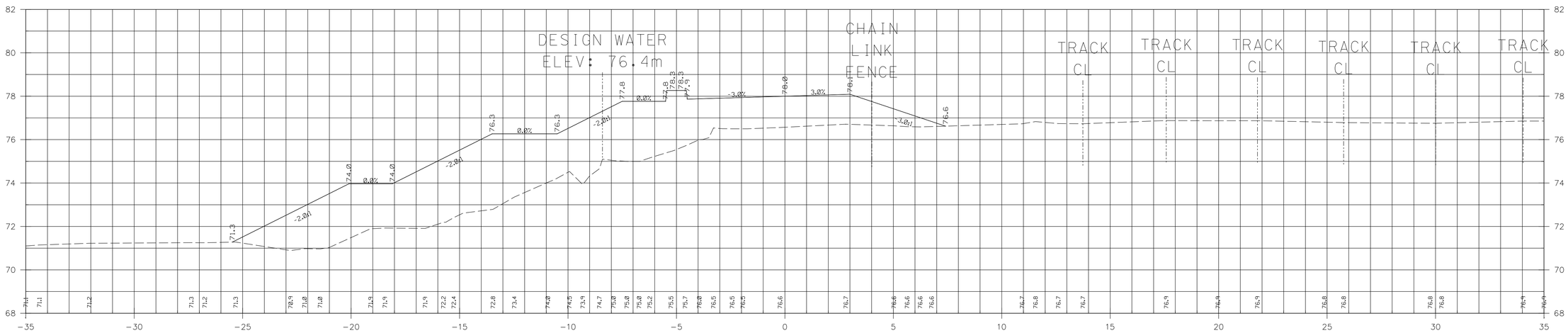


1+480.00

SCALE: 1:100 STA 1+520.00 TO STA 1+540.00

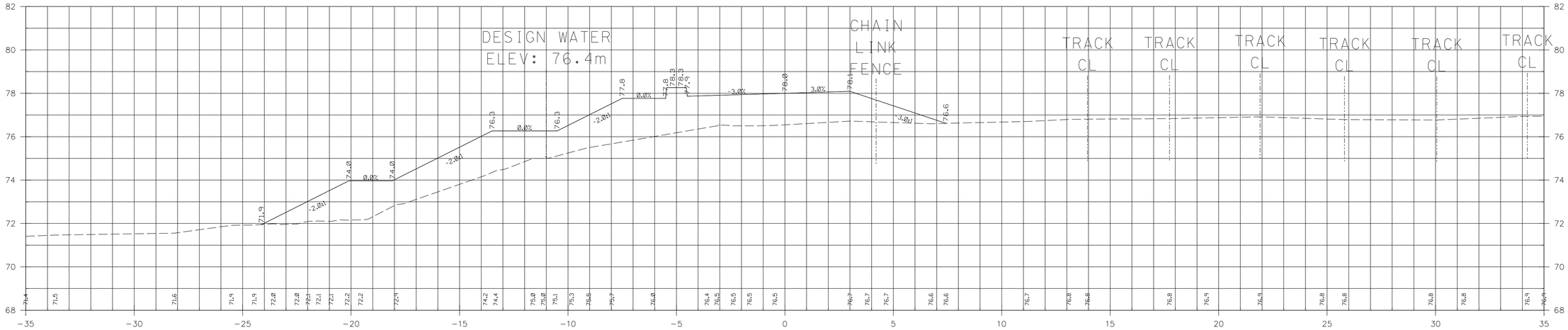


1+540.00

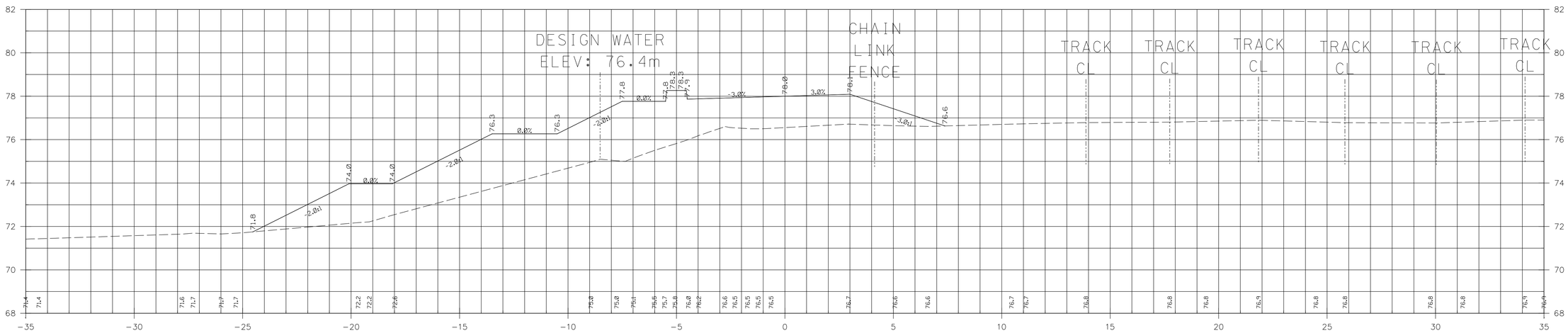


1+520.00

SCALE: 1:100 STA 1+560.00 TO STA 1+580.00

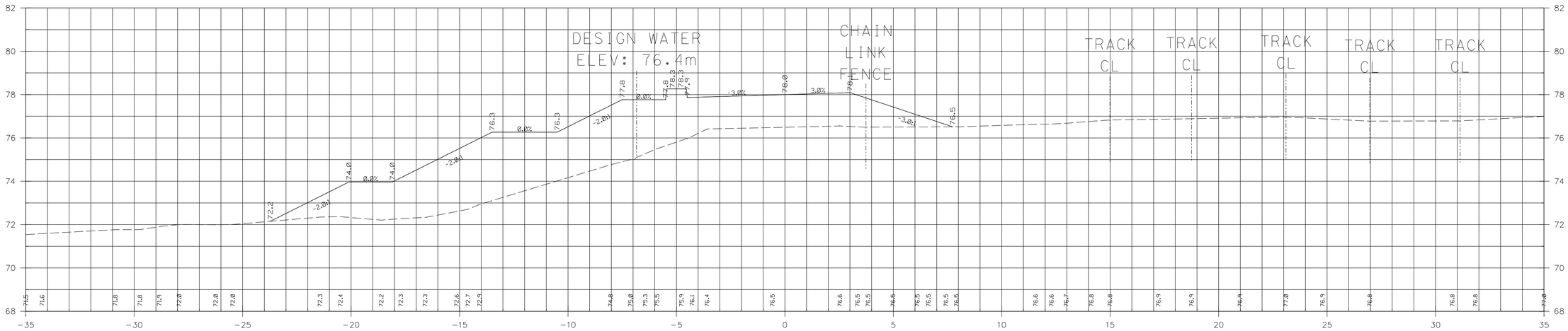


1+580.00

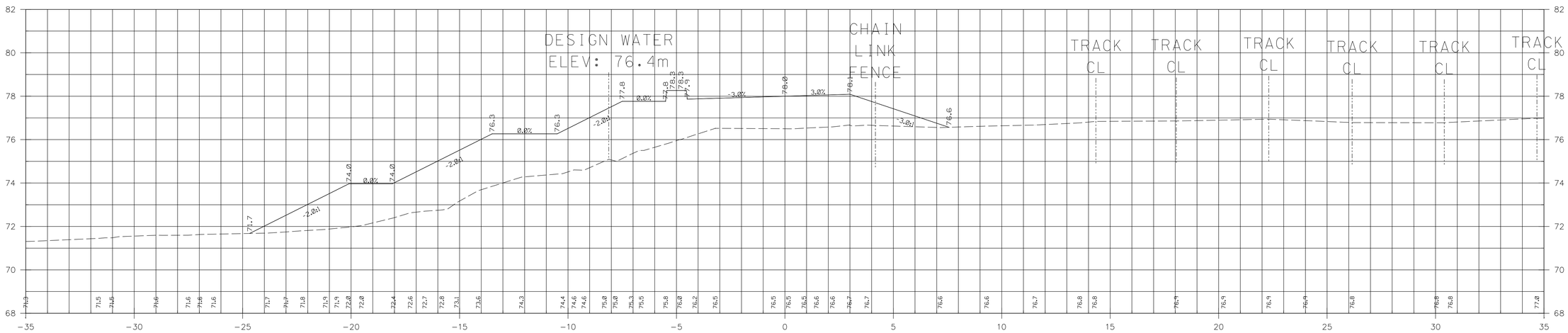


1+560.00

SCALE: 1:100 STA 1+600.00 TO STA 1+620.00

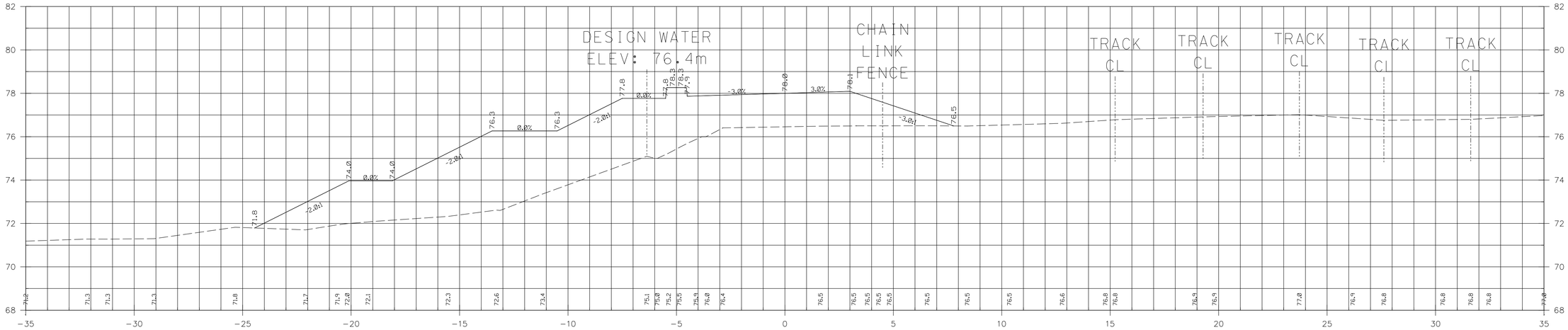


1+620.00

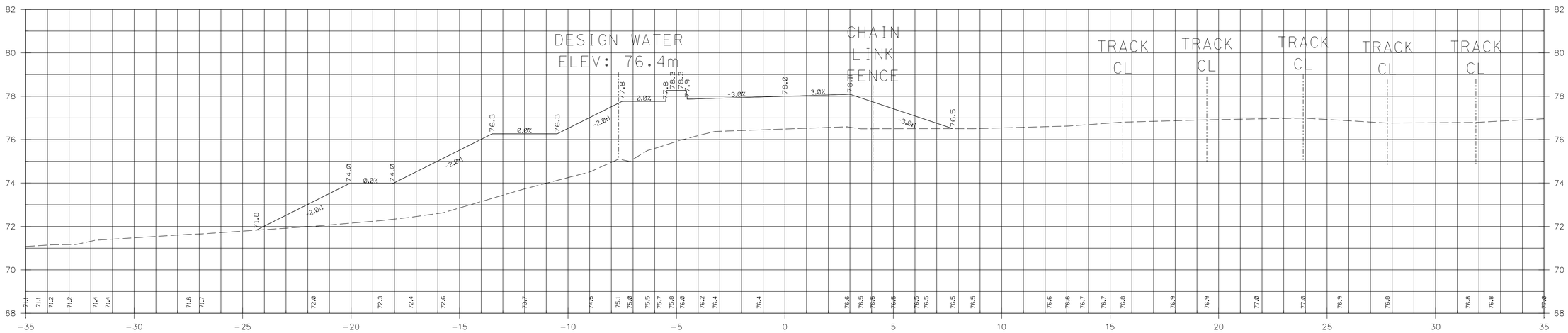


1+600.00

SCALE: 1:100 STA 1+640.00 TO STA 1+660.00

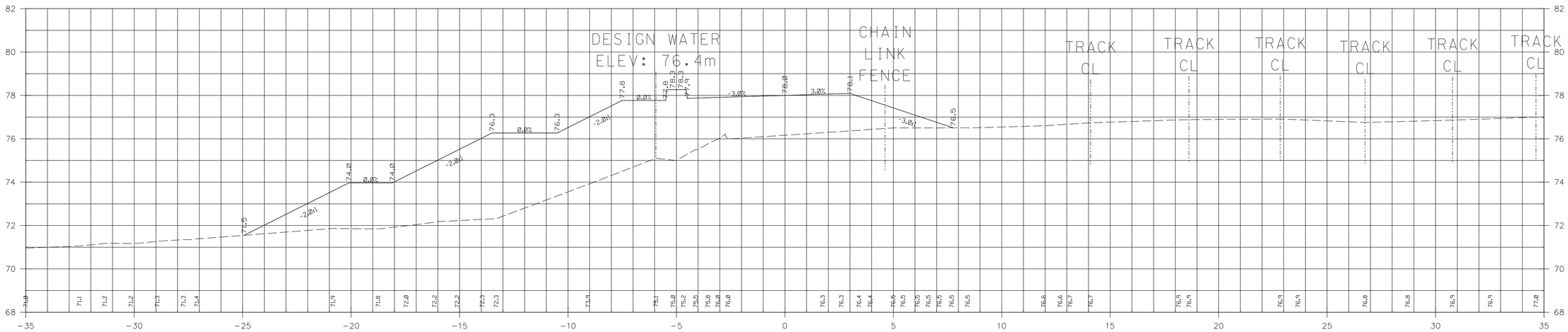


1+660.00

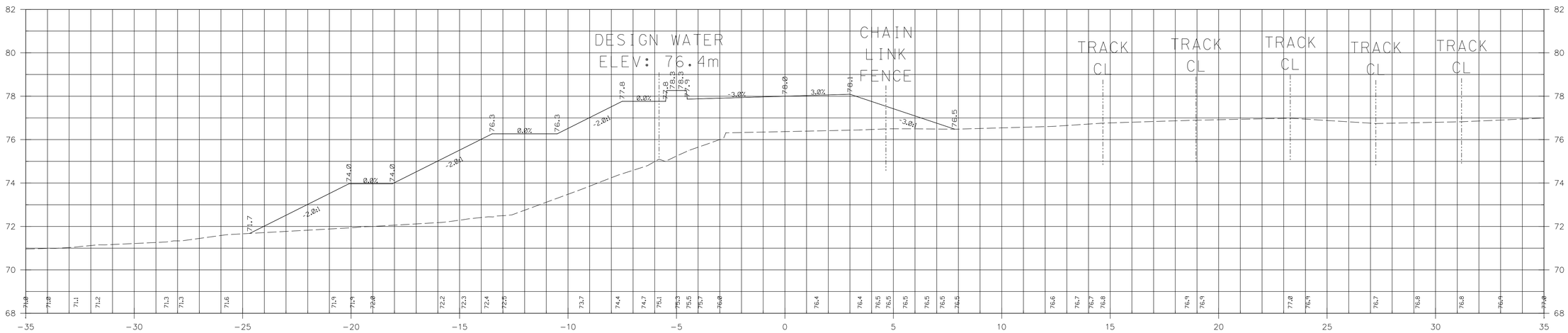


1+640.00

SCALE: 1:100 STA 1+680.00 TO STA 1+700.00

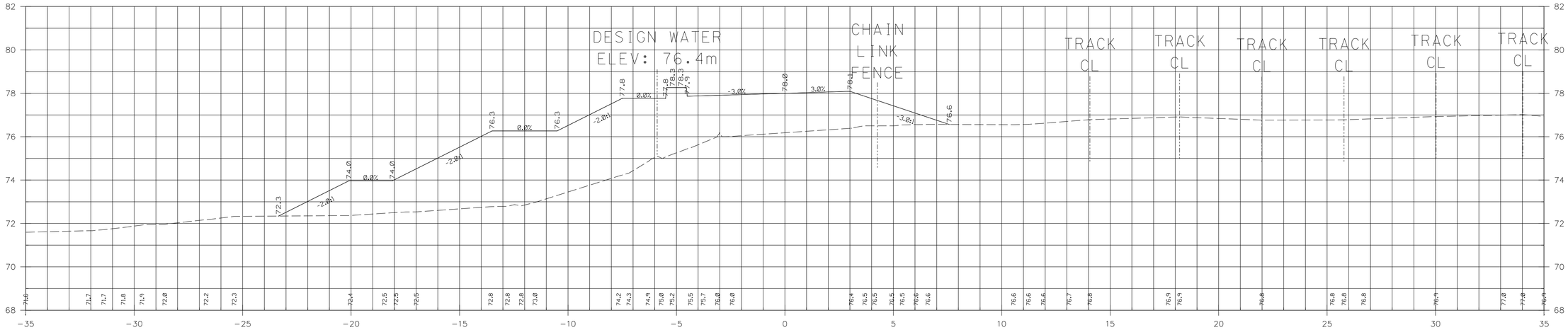


1+700.00

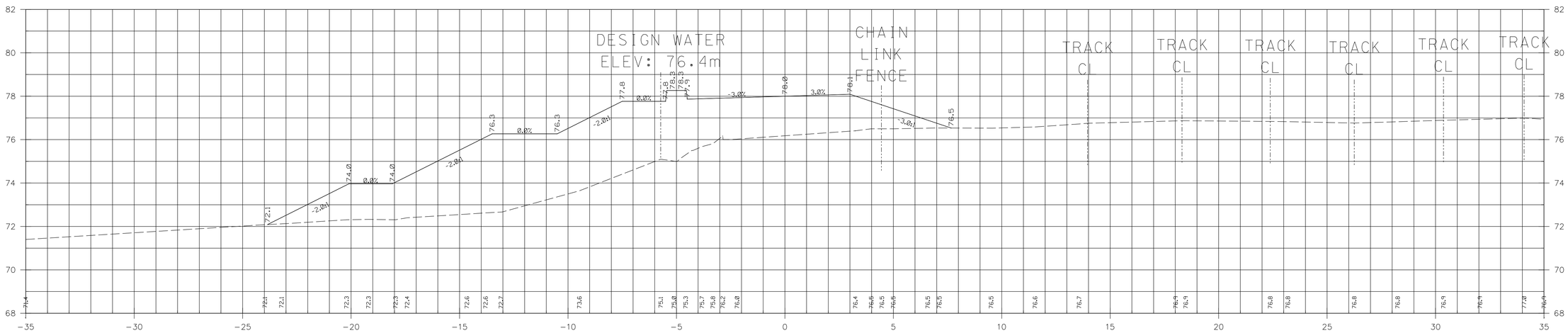


1+680.00

SCALE: 1:100 STA 1+720.00 TO STA 1+740.00

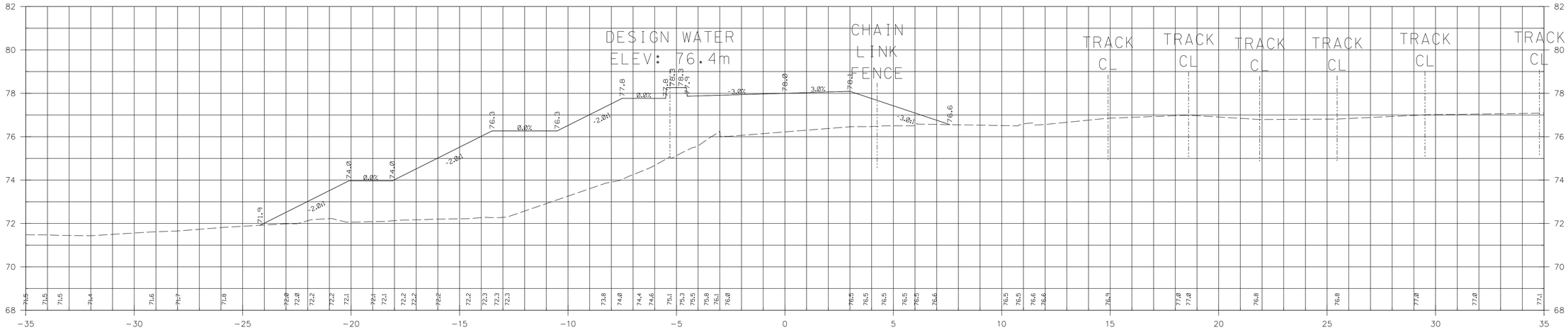


1+740.00

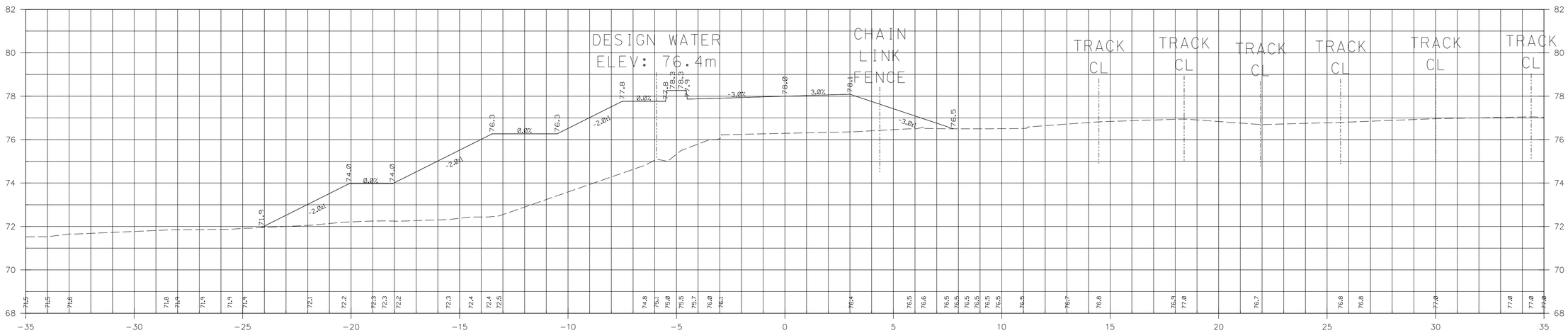


1+720.00

SCALE: 1:100 STA 1+760.00 TO STA 1+780.00

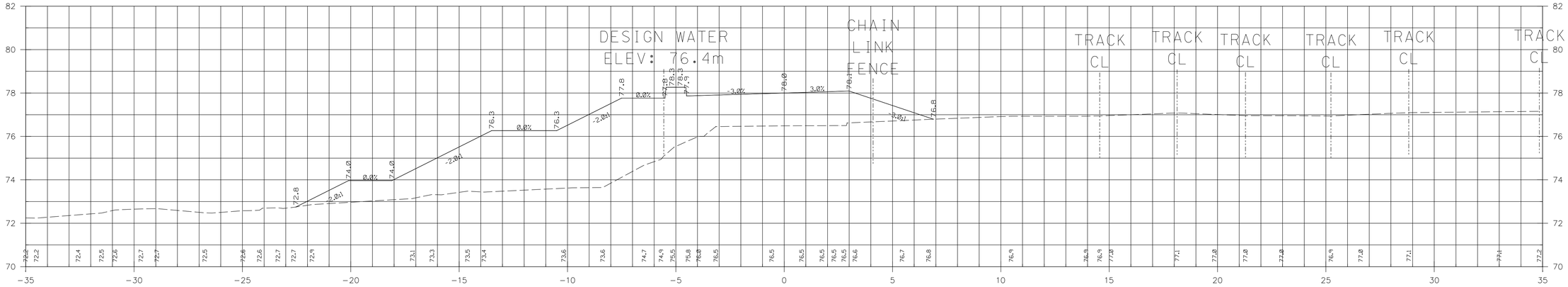


1+780.00

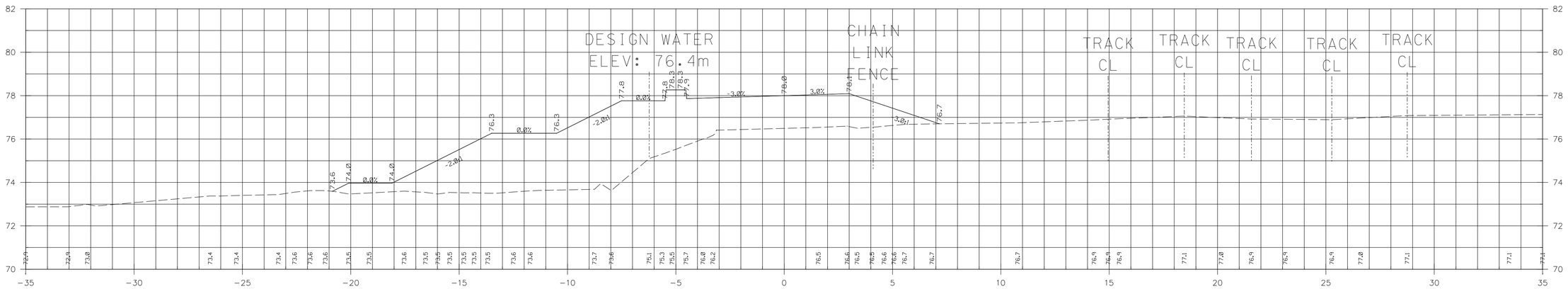


1+760.00

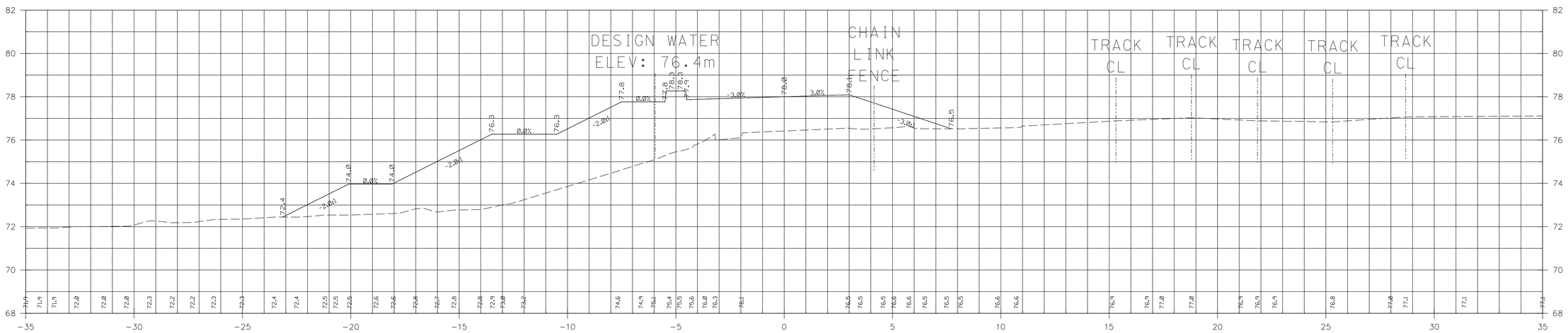
SCALE: 1:100 STA 1+800.00 TO STA 1+840.00



1+840.00

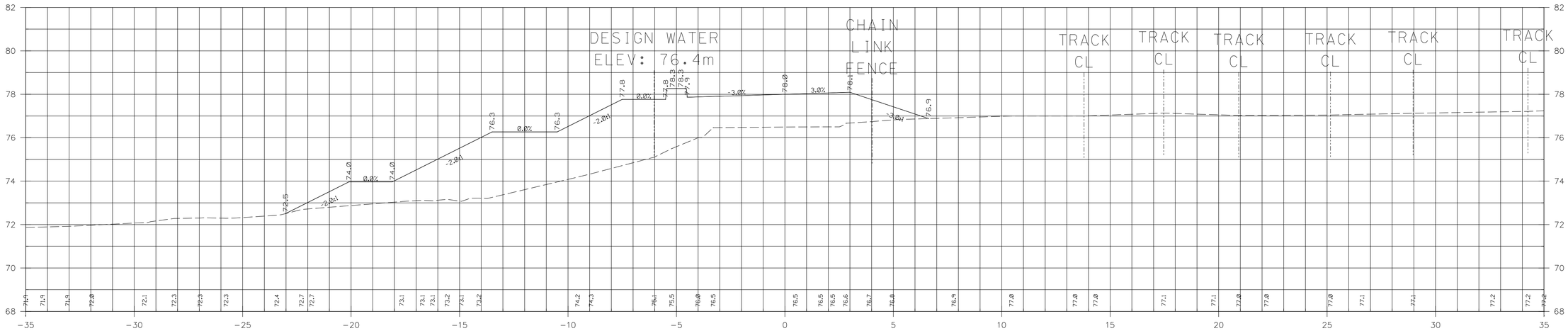


1+820.00

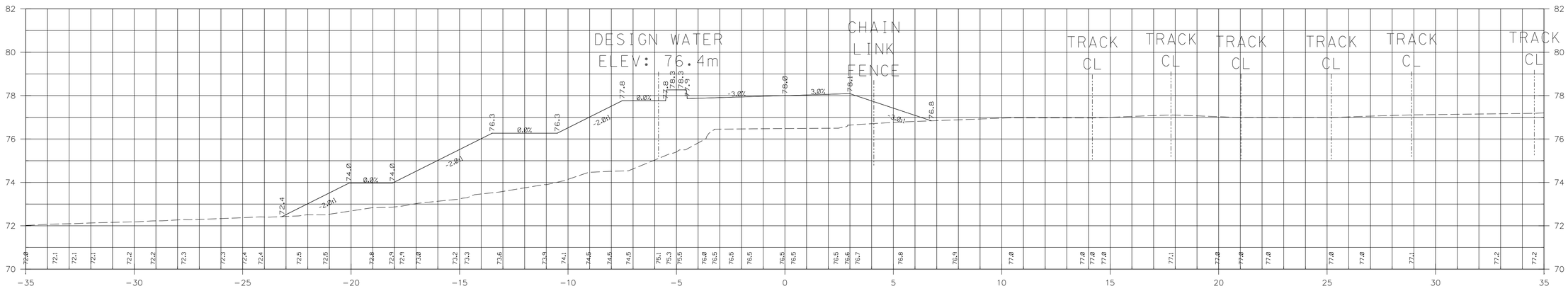


1+800.00

SCALE: 1:100 STA 1+860.00 TO STA 1+880.00

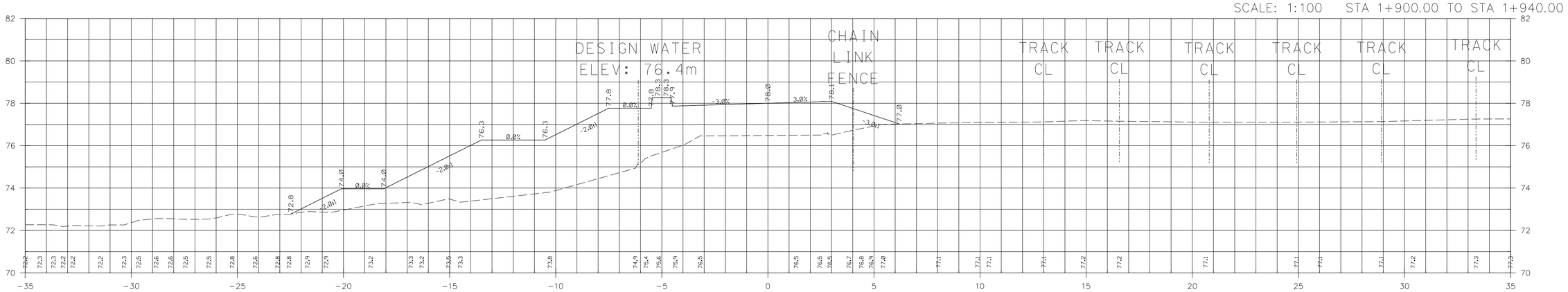


1+880.00



1+860.00

SCALE: 1:100 STA 1+900.00 TO STA 1+940.00



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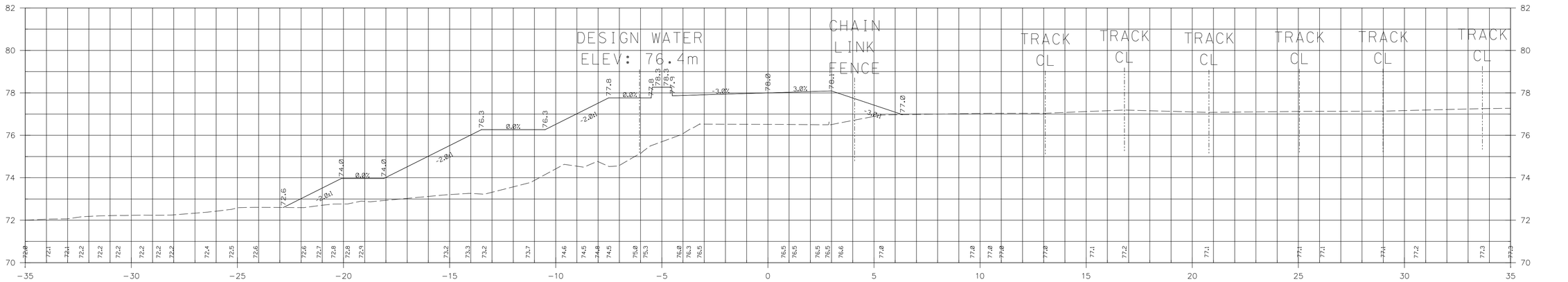

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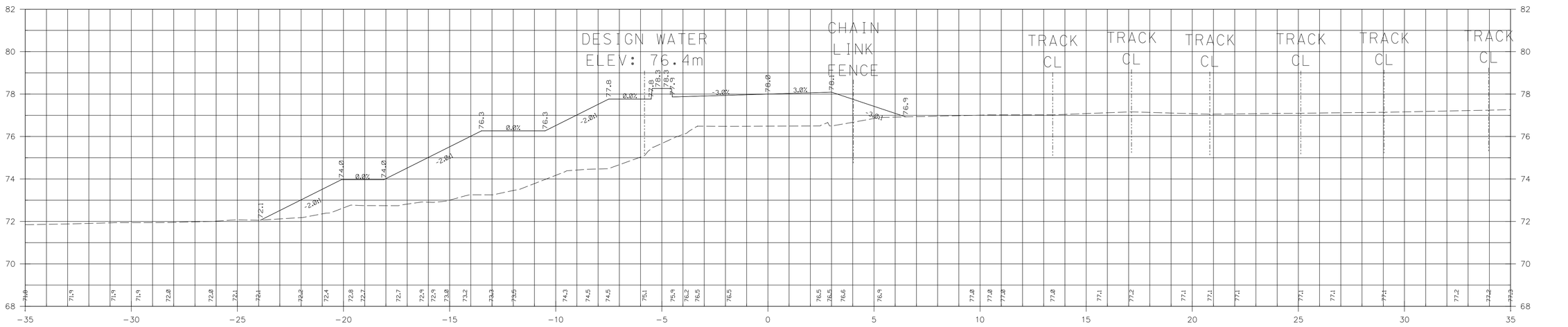
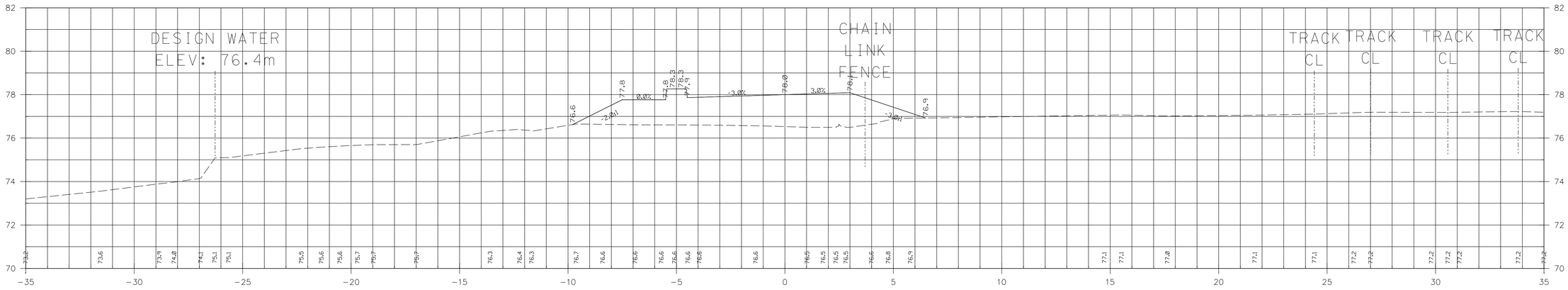


1+900.00

SCALE: 1:100 STA 1+960.00 TO STA 2+000.00



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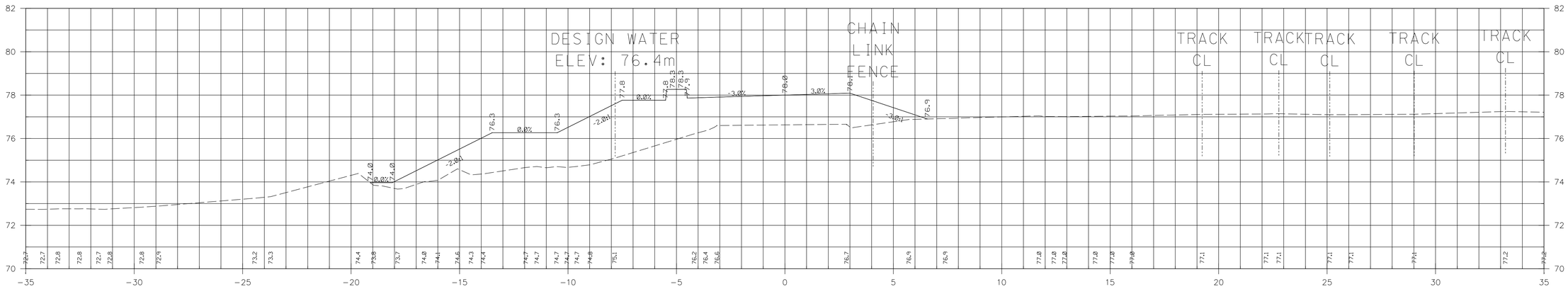

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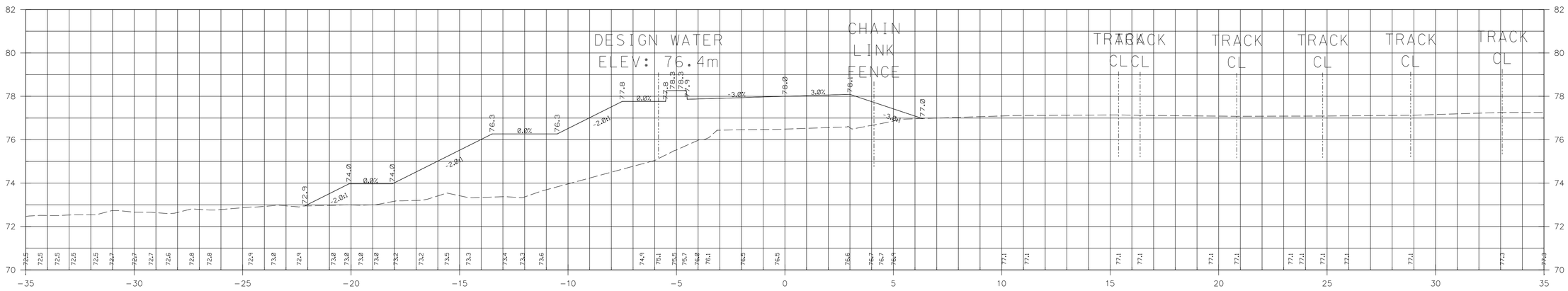
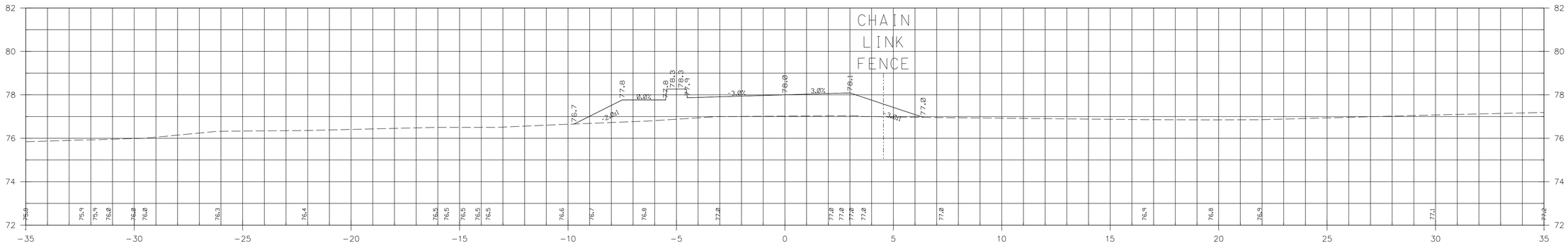


1+960.00

SCALE: 1:100 STA 2+020.00 TO STA 2+060.00



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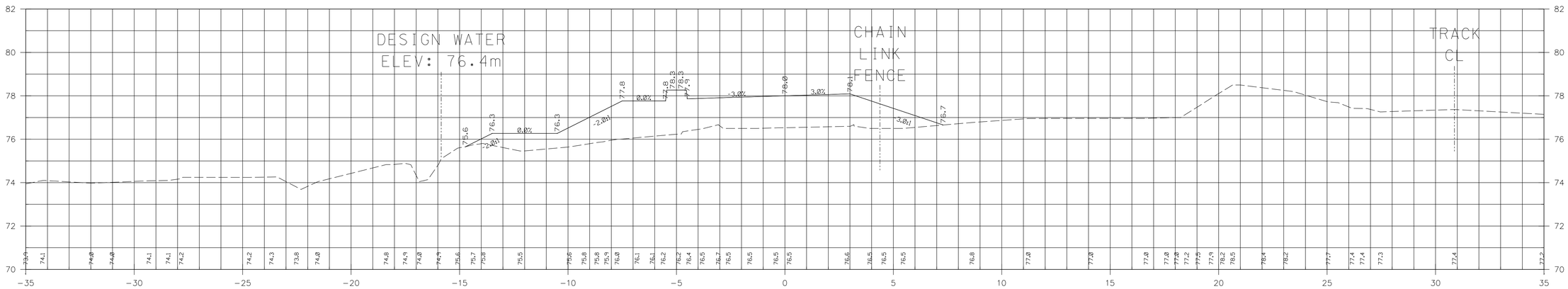
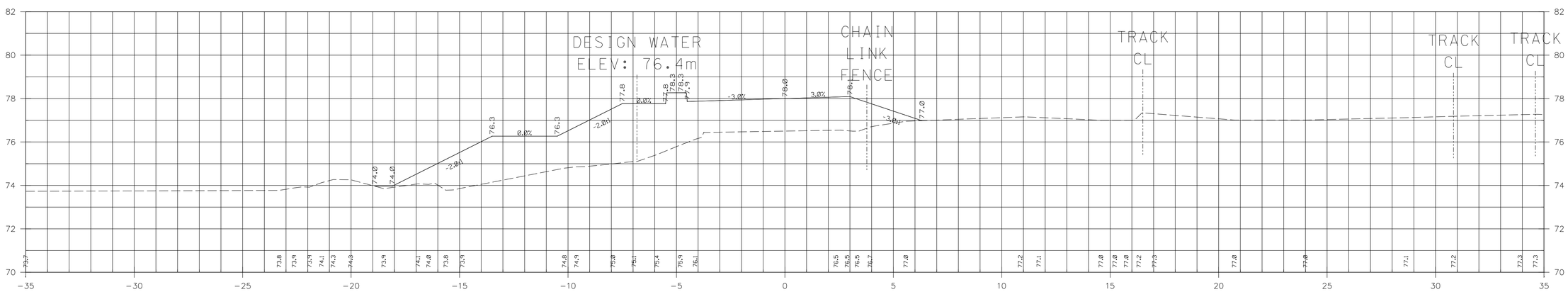
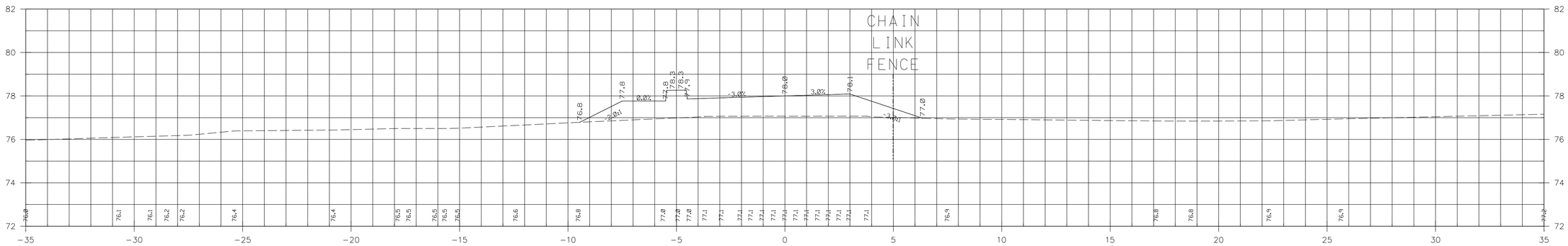


2+040.00



2+020.00

SCALE: 1:100 STA 2+062.16 TO STA 2+062.16



2+062.16

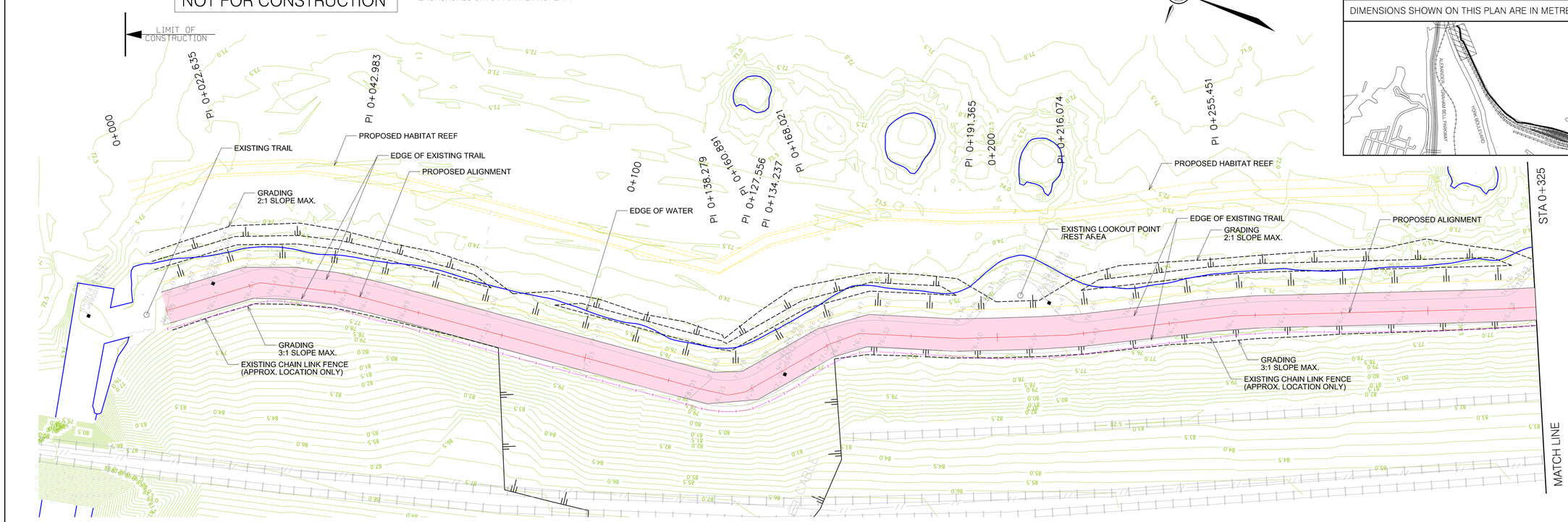
HAMILTON HARBOUR WATERFRONT TRAIL

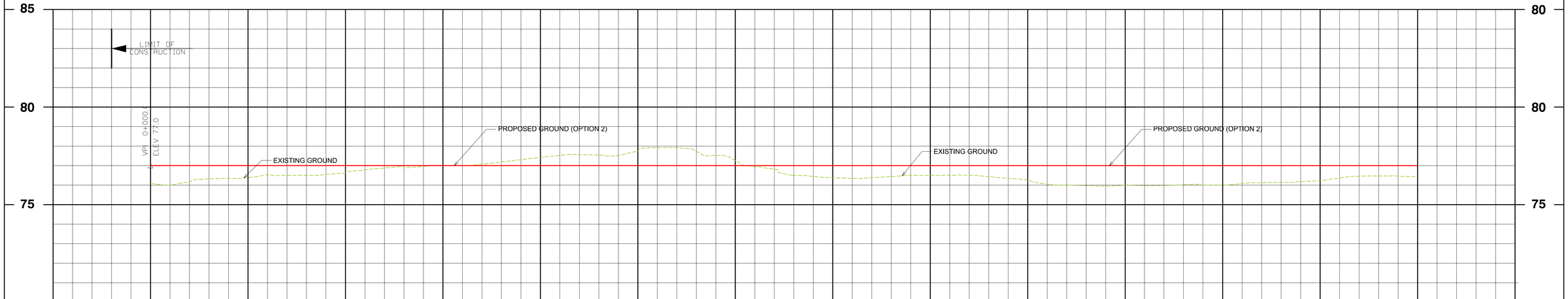
PRELIMINARY
NOT FOR CONSTRUCTION

DESIGN NOTE:
RETAINING WALL TO BE PROPOSED AT LOCATIONS WHERE GRADING ENCROACHES ONTO PRIVATE PROPERTY

FILE No.	CONTRACT No. -	SHEET No.
	DRAWING No. -	1 OF 7

DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED





PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL PROFILE ELEVATIONS	76.1	76.4	76.6	77.0	77.4	77.7	77.3	76.4	76.5	76.3	76.0	76.0	76.2	76.5	EXISTING ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	0+000	0+025	0+050	0+075	0+100	0+125	0+150	0+175	0+200	0+225	0+250	0+275	0+300	0+325	EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
HORIZONTAL 1:500 (0, 5m, 10m, 20m)
VERTICAL 1:100 (0, 1m, 2m, 4m)

DESIGNER
Jason Park

PROJECT ENGINEER
Norton Chu, P. Eng.

CITY OF HAMILTON
Public Works Department

HAMILTON HARBOUR WATERFRONT TRAIL
OPTION 2 - SHORELINE PROTECTION (PROP. ELEV.: 76.5m)
From : STATION 0+000
To : STATION 0+325

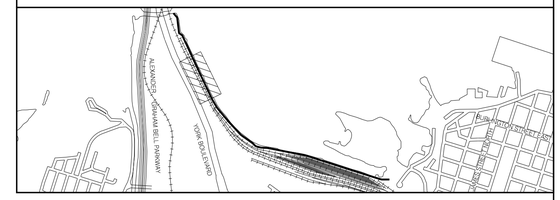
HAMILTON HARBOUR WATERFRONT TRAIL

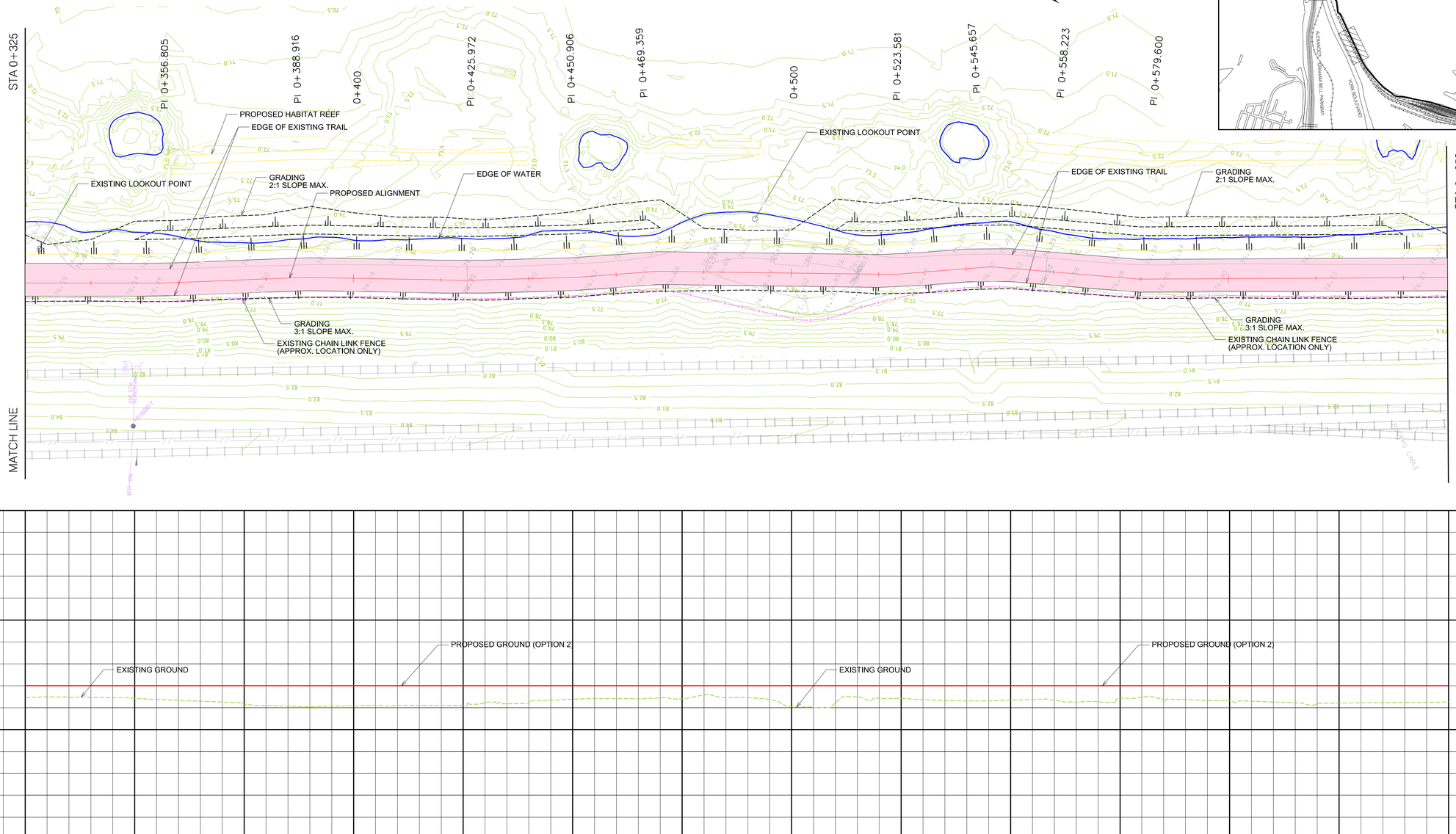
PRELIMINARY
NOT FOR CONSTRUCTION

DESIGN NOTE:
RETAINING WALL TO BE PROPOSED AT LOCATIONS WHERE GRADING ENCROACHES ONTO PRIVATE PROPERTY

FILE No.	CONTRACT No. - DRAWING No. -	SHEET No. 2 OF 7

DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED





PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL PROFILE ELEVATIONS	76.5	76.4	76.2	76.1	76.1	76.4	76.4	76.0	76.4	76.3	76.4	76.3	76.2	76.3	EXISTING ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	0+325	0+350	0+375	0+400	0+425	0+450	0+475	0+500	0+525	0+550	0+575	0+600	0+625	0+650	EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
HORIZONTAL 1:500 (0, 5m, 10m, 20m)
VERTICAL 1:100 (0, 1m, 2m, 4m)

DESIGNER
Jason Park

PROJECT ENGINEER
Norton Chu, P. Eng.

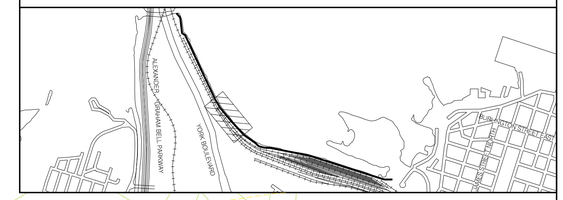
CITY OF HAMILTON
Public Works Department

HAMILTON HARBOUR WATERFRONT TRAIL
OPTION 2 - SHORELINE PROTECTION (PROP. ELEV.: 76.5m)
From : STATION 0+325
To : STATION 0+650

HAMILTON HARBOUR WATERFRONT TRAIL

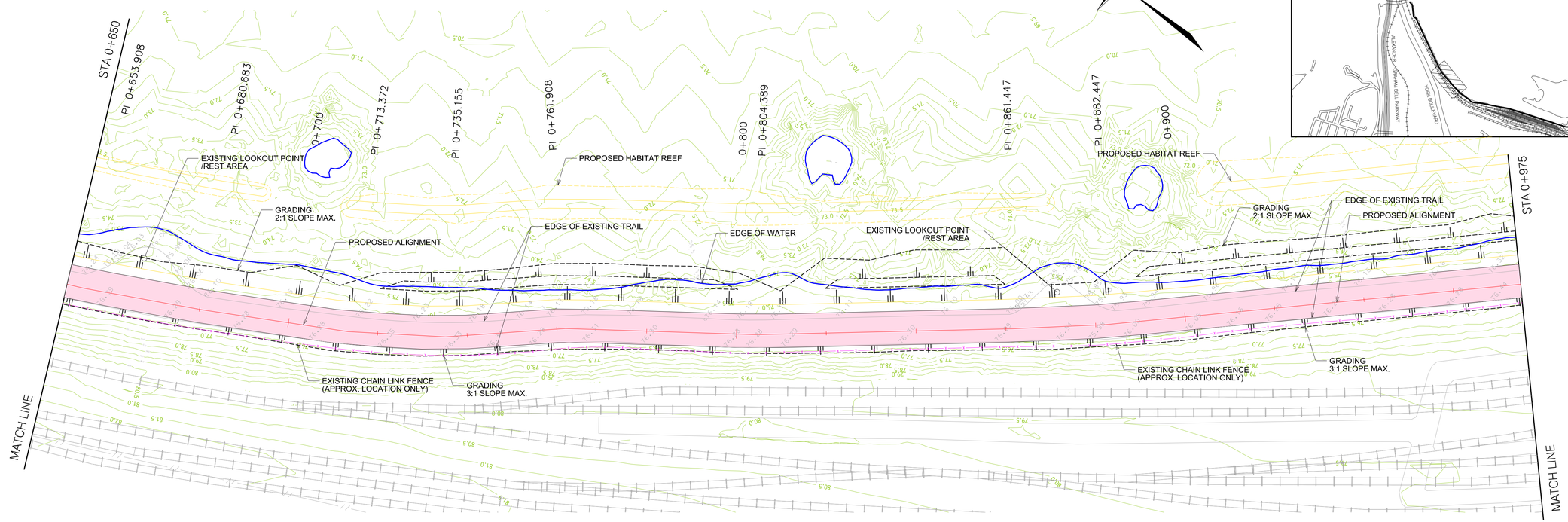
FILE No.	CONTRACT No. - DRAWING No. -	SHEET No. 3 OF 7

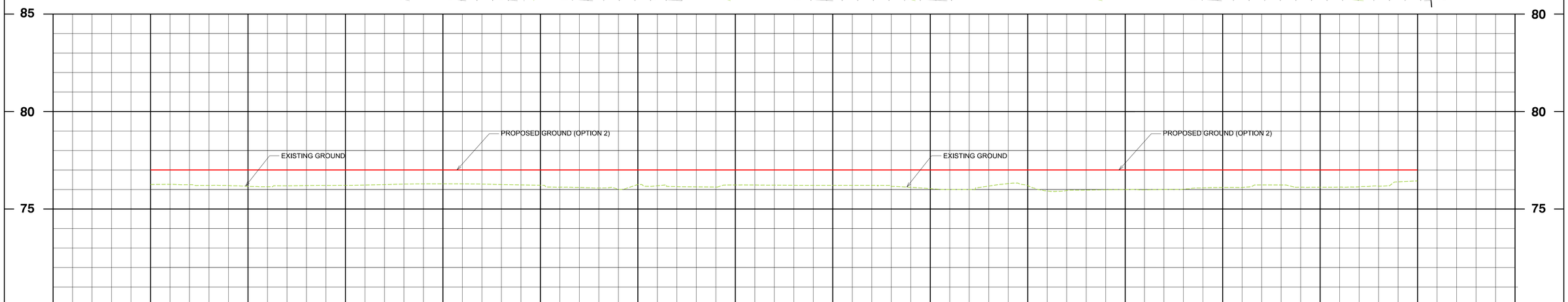
DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED



PRELIMINARY
NOT FOR CONSTRUCTION

DESIGN NOTE:
RETAINING WALL TO BE PROPOSED AT LOCATIONS WHERE GRADING ENCROACHES ONTO PRIVATE PROPERTY





PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL PROFILE ELEVATIONS	76.3	76.2	76.2	76.3	76.2	76.3	76.2	76.2	76.0	76.2	76.0	76.1	76.1	76.4	EXISTING ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	0+650	0+675	0+700	0+725	0+750	0+775	0+800	0+825	0+850	0+875	0+900	0+925	0+950	0+975	EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
HORIZONTAL 1:500 (0, 5m, 10m, 20m)
VERTICAL 1:100 (0, 1m, 2m, 4m)

DESIGNER
Jason Park

PROJECT ENGINEER
Norton Chu, P. Eng.

CITY OF HAMILTON
Public Works Department

HAMILTON HARBOUR WATERFRONT TRAIL

OPTION 2 - SHORELINE PROTECTION (PROP. ELEV.: 76.5m)

From : STATION 0+650
To : STATION 0+975

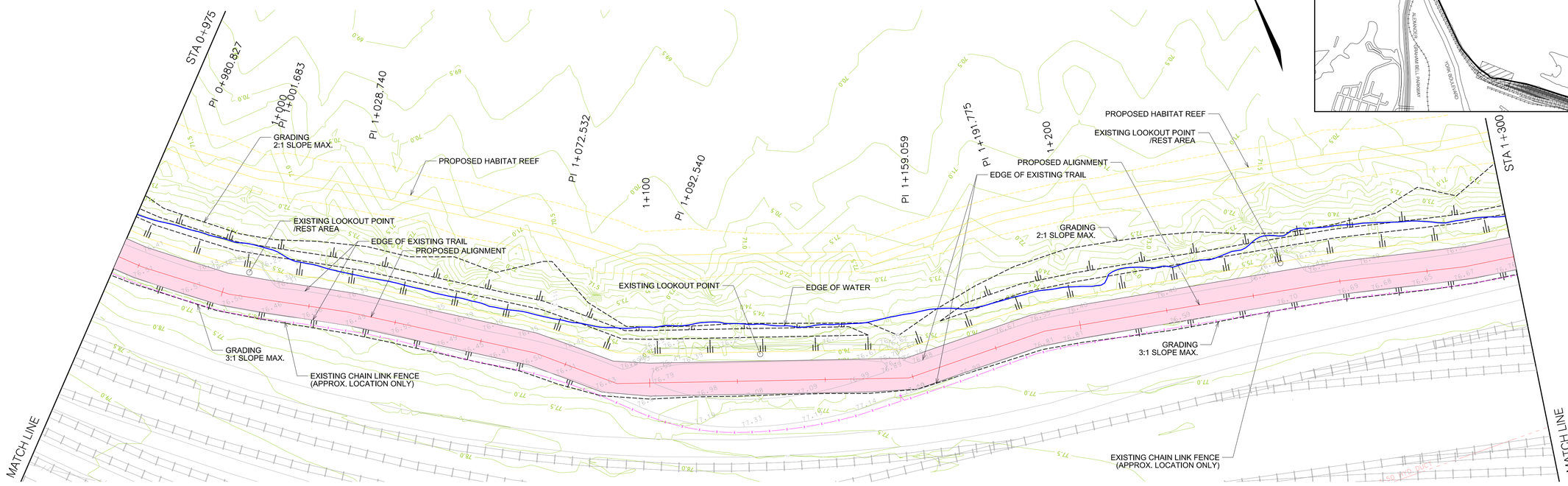
HAMILTON HARBOUR WATERFRONT TRAIL

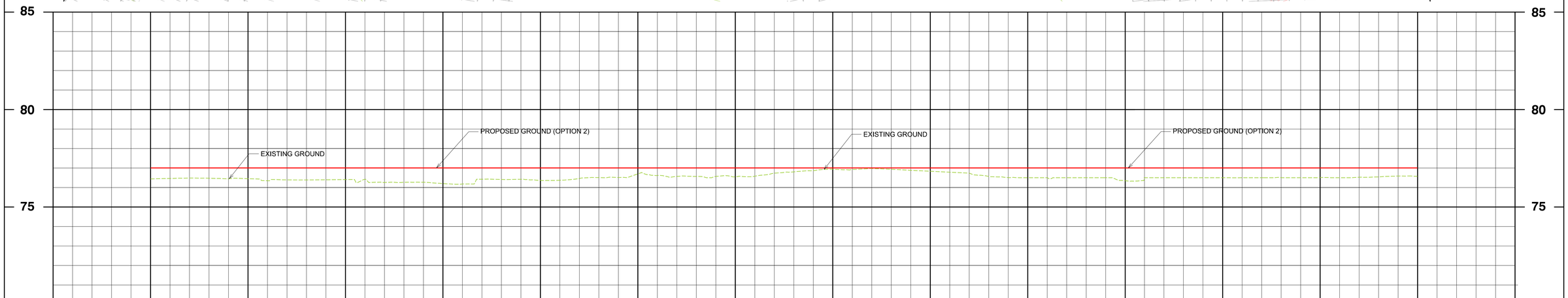
FILE No.	CONTRACT No. - DRAWING No. -	SHEET No. 4 OF 7

DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED

PRELIMINARY
NOT FOR CONSTRUCTION

DESIGN NOTE:
RETAINING WALL TO BE PROPOSED AT LOCATIONS WHERE GRADING ENCROACHES ONTO PRIVATE PROPERTY





	0+975	1+000	1+025	1+050	1+075	1+100	1+125	1+150	1+175	1+200	1+225	1+250	1+275	1+300
PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5
EXISTING ℄ OF TRAIL PROFILE ELEVATIONS	76.4	76.4	76.4	76.2	76.4	76.7	76.5	76.9	76.8	76.5	76.3	76.5	76.5	76.6
EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	0+975	1+000	1+025	1+050	1+075	1+100	1+125	1+150	1+175	1+200	1+225	1+250	1+275	1+300

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
HORIZONTAL 1:500 (0, 5m, 10m, 20m)
VERTICAL 1:100 (0, 1m, 2m, 4m)

DESIGNER
Jason Park

PROJECT ENGINEER
Norton Chu, P. Eng.

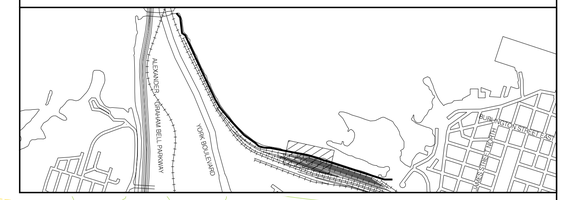
CITY OF HAMILTON
Public Works Department

HAMILTON HARBOUR WATERFRONT TRAIL
OPTION 2 - SHORELINE PROTECTION (PROP. ELEV.: 76.5m)
From : STATION 0+975
To : STATION 1+300

HAMILTON HARBOUR WATERFRONT TRAIL

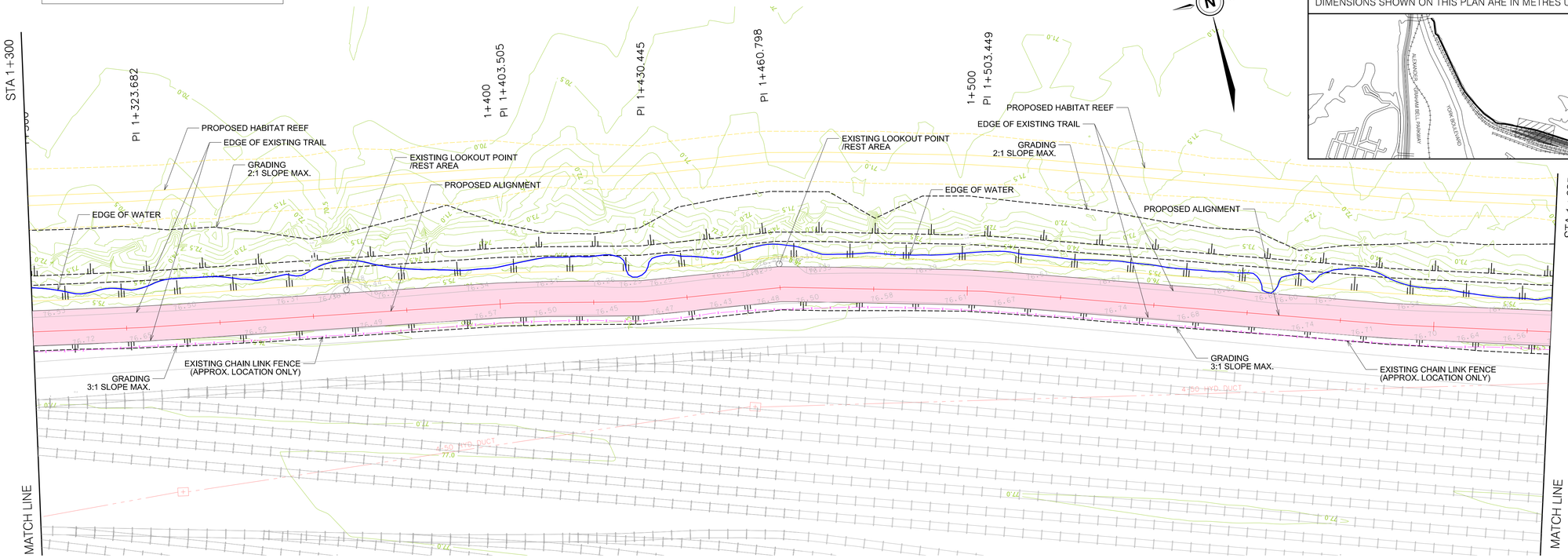
FILE No.	CONTRACT No. - DRAWING No. -	SHEET No. 5 OF 7

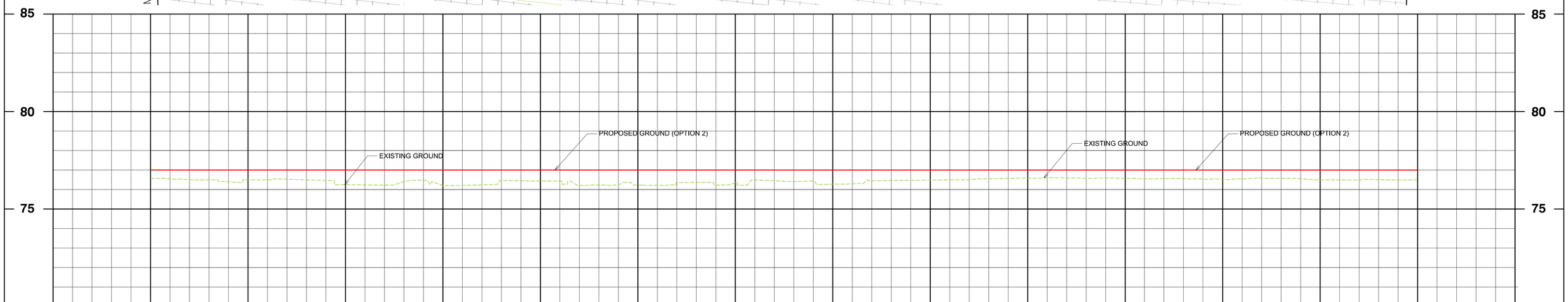
DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED



PRELIMINARY
NOT FOR CONSTRUCTION

DESIGN NOTE:
RETAINING WALL TO BE PROPOSED AT LOCATIONS WHERE GRADING ENCROACHES ONTO PRIVATE PROPERTY





PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL PROFILE ELEVATIONS	76.6	76.5	76.2	76.2	76.4	76.2	76.4	76.3	76.5	76.6	76.6	76.5	76.5	76.5	EXISTING ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	1+300	1+325	1+350	1+375	1+400	1+425	1+450	1+475	1+500	1+525	1+550	1+575	1+600	1+625	EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
HORIZONTAL 1:500 (0, 5m, 10m, 20m)
VERTICAL 1:100 (0, 1m, 2m, 4m)

DESIGNER
Jason Park

PROJECT ENGINEER
Norton Chu, P. Eng.

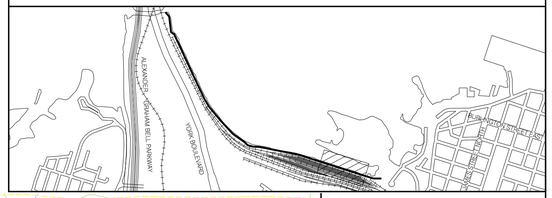
CITY OF HAMILTON
Public Works Department

HAMILTON HARBOUR WATERFRONT TRAIL
OPTION 2 - SHORELINE PROTECTION (PROP. ELEV.: 76.5m)
From : STATION 1+300
To : STATION 1+625

HAMILTON HARBOUR WATERFRONT TRAIL

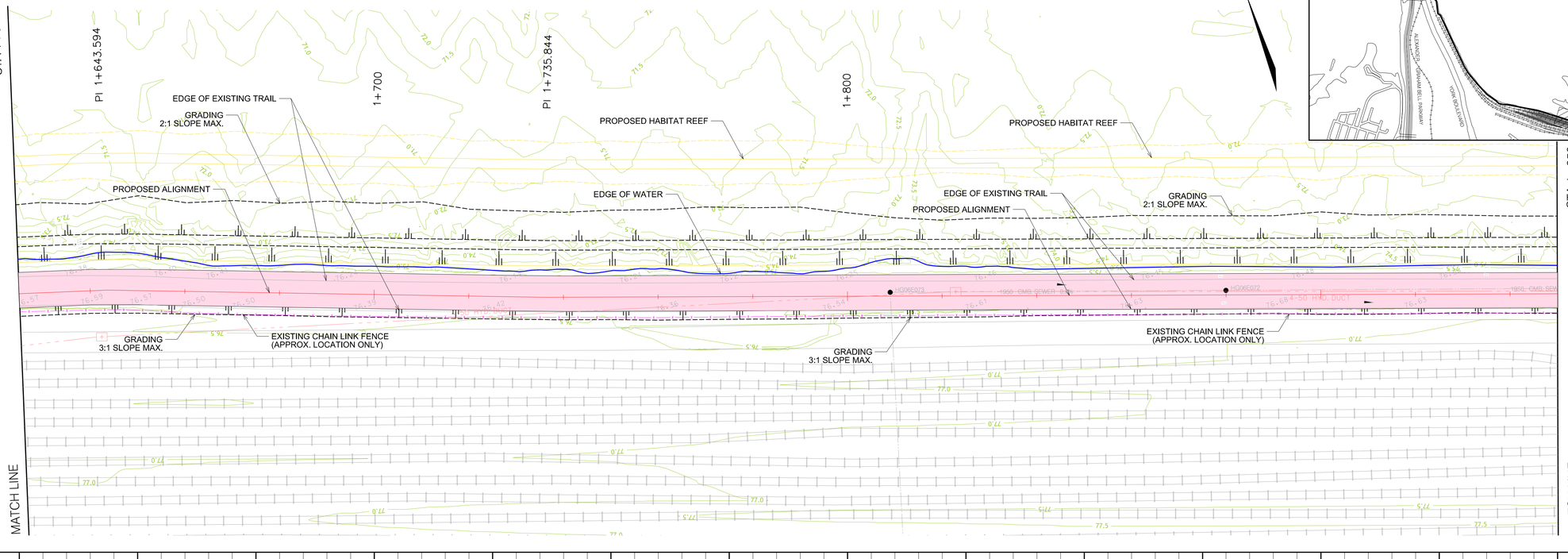
FILE No.	CONTRACT No. - DRAWING No. -	SHEET No. 6 OF 7

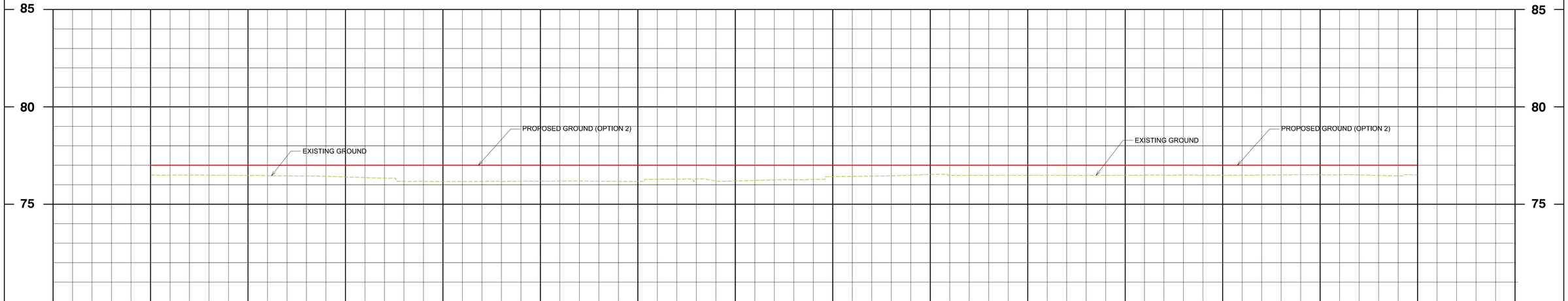
DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED



PRELIMINARY
NOT FOR CONSTRUCTION

DESIGN NOTE:
RETAINING WALL TO BE PROPOSED AT LOCATIONS WHERE GRADING ENCROACHES ONTO PRIVATE PROPERTY





PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL PROFILE ELEVATIONS	76.5	76.5	76.4	76.2	76.2	76.2	76.2	76.4	76.5	76.5	76.5	76.5	76.5	76.5	EXISTING ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	1+625	1+650	1+675	1+700	1+725	1+750	1+775	1+800	1+825	1+850	1+875	1+900	1+925	1+950	EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
HORIZONTAL 1:500 (0, 5m, 10m, 20m)
VERTICAL 1:100 (0, 1m, 2m, 4m)

DESIGNER
Jason Park

PROJECT ENGINEER
Norton Chu, P. Eng.

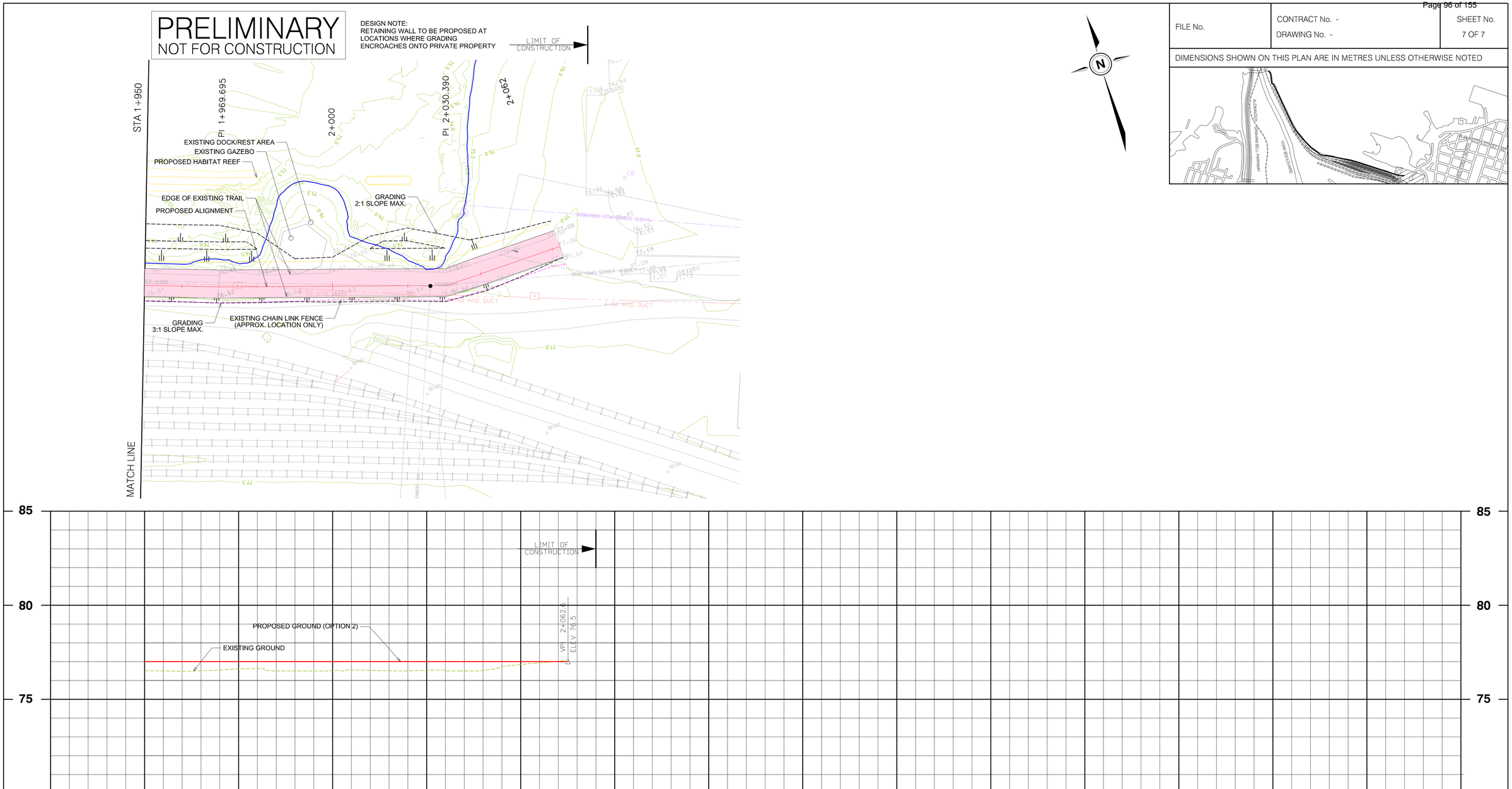
CITY OF HAMILTON
Public Works Department

HAMILTON HARBOUR WATERFRONT TRAIL
OPTION 2 - SHORELINE PROTECTION (PROP. ELEV.: 76.5m)
From : STATION 1+625
To : STATION 1+950

HAMILTON HARBOUR WATERFRONT TRAIL

FILE No.	CONTRACT No. - DRAWING No. -	SHEET No. 7 OF 7

DIMENSIONS SHOWN ON THIS PLAN ARE IN METRES UNLESS OTHERWISE NOTED



PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS	76.5	76.5	76.5	76.5	76.5		PROPOSED ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL PROFILE ELEVATIONS	76.5	76.6	76.5	76.5	76.8		EXISTING ℄ OF TRAIL PROFILE ELEVATIONS
EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE	1+950	1+975	2+000	2+025	2+050	2+075	2+100	EXISTING ℄ OF TRAIL ALLOWANCE CHAINAGE

No.	REVISIONS	INITIAL	DATE
1	PRELIMINARY TRAIL LAYOUT	N.C.	12/2019

DRAWN BY: J.P. DATE: DECEMBER 6 2019

REFERENCE MATERIAL:
Base Information : CITY OF HAMILTON

Geodetic Bench Mark Index No. X-XX Elevation=XX.XXXm
Borehole Report -

SCALES
0 5m 10m 20m
HORIZONTAL 1:500
0 1m 2m 4m
VERTICAL 1:100

DESIGNER
Jason Park

PROJECT ENGINEER
Norton Chu, P. Eng.

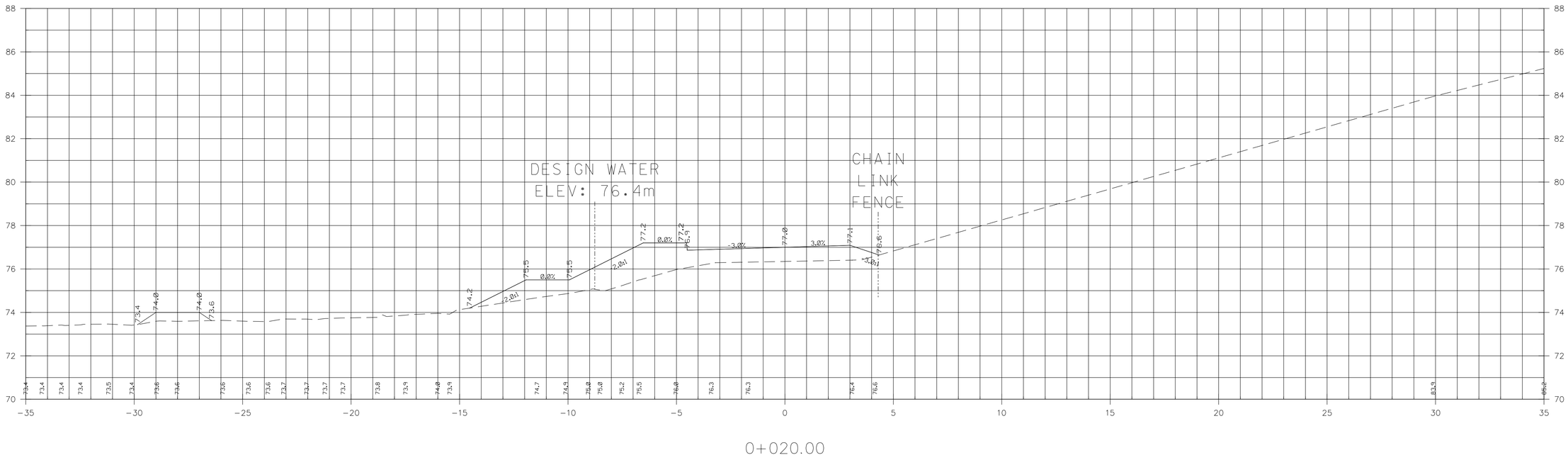
CITY OF HAMILTON
Public Works Department

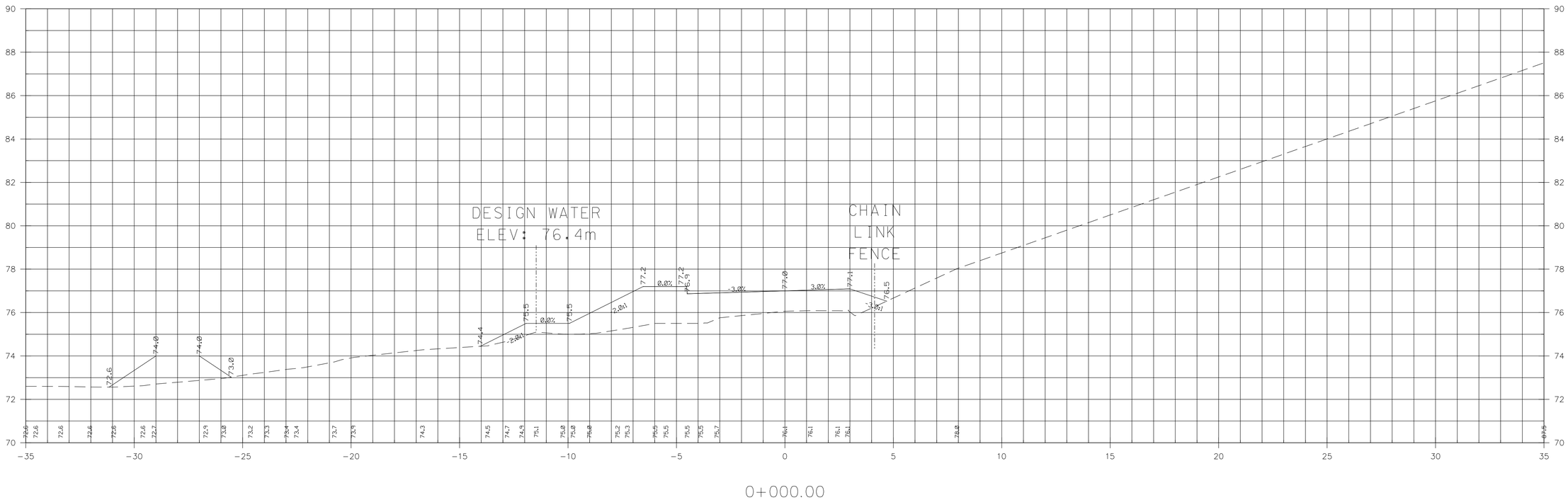
HAMILTON HARBOUR WATERFRONT TRAIL

OPTION 2 - SHORELINE PROTECTION (PROP. ELEV.: 76.5m)

From : STATION 1+950
To : STATION 2+070

SCALE: 1:100 STA 0+000.00 TO STA 0+020.00





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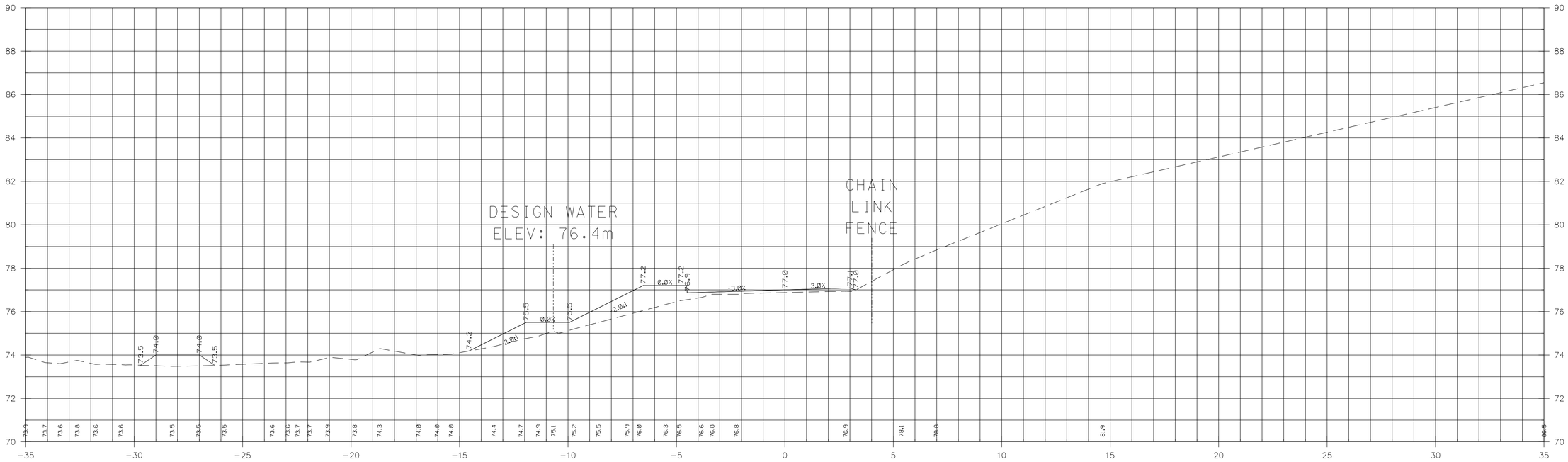

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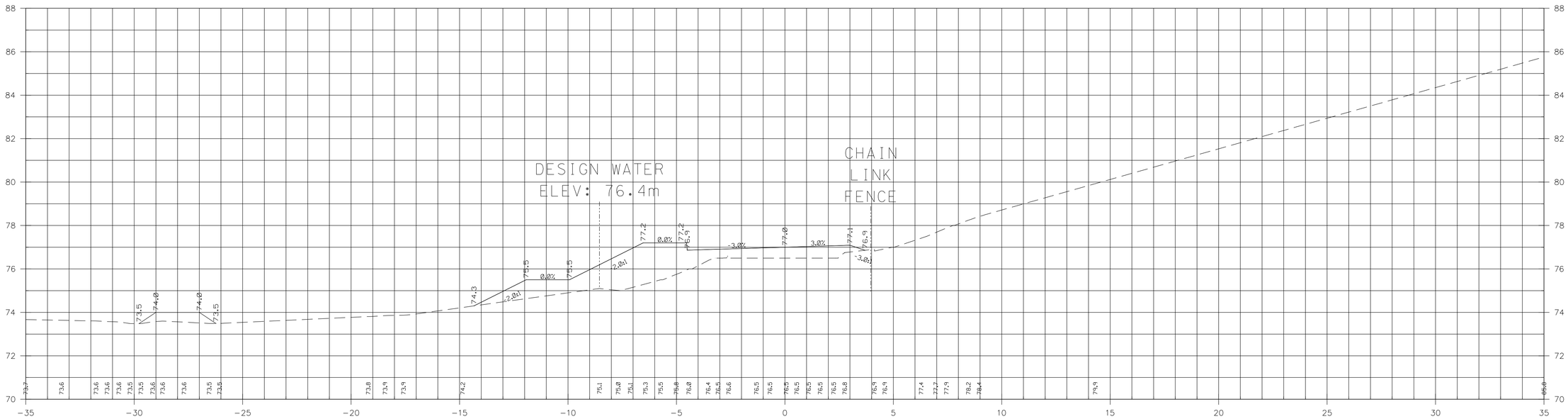

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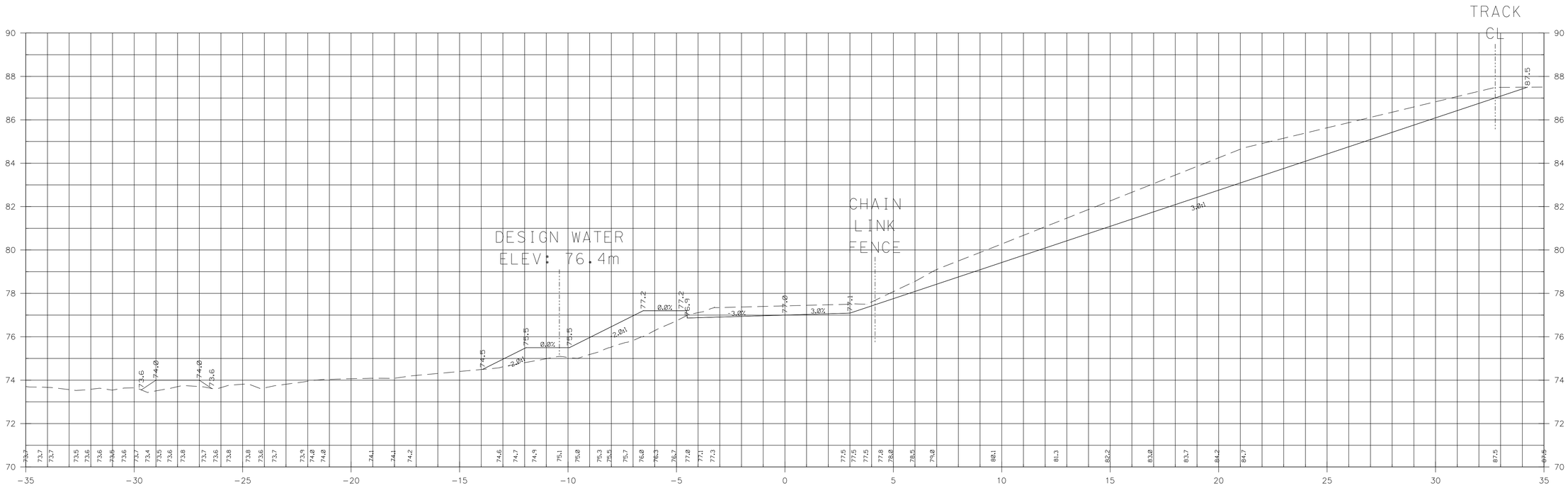
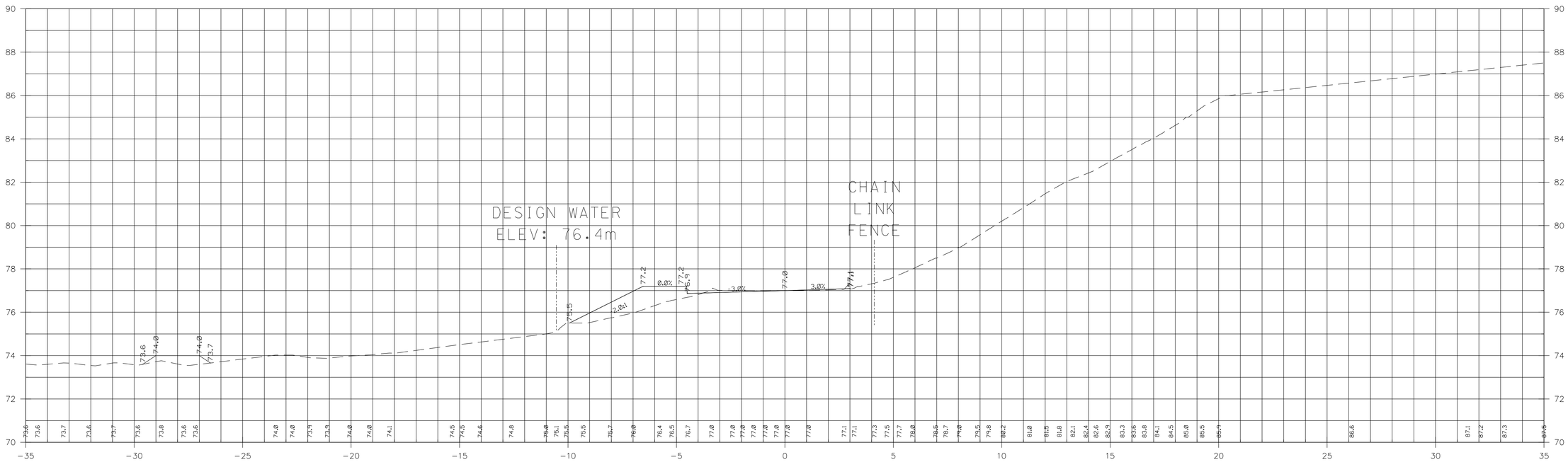
SCALE: 1:100 STA 0+080.00 TO STA 0+100.00





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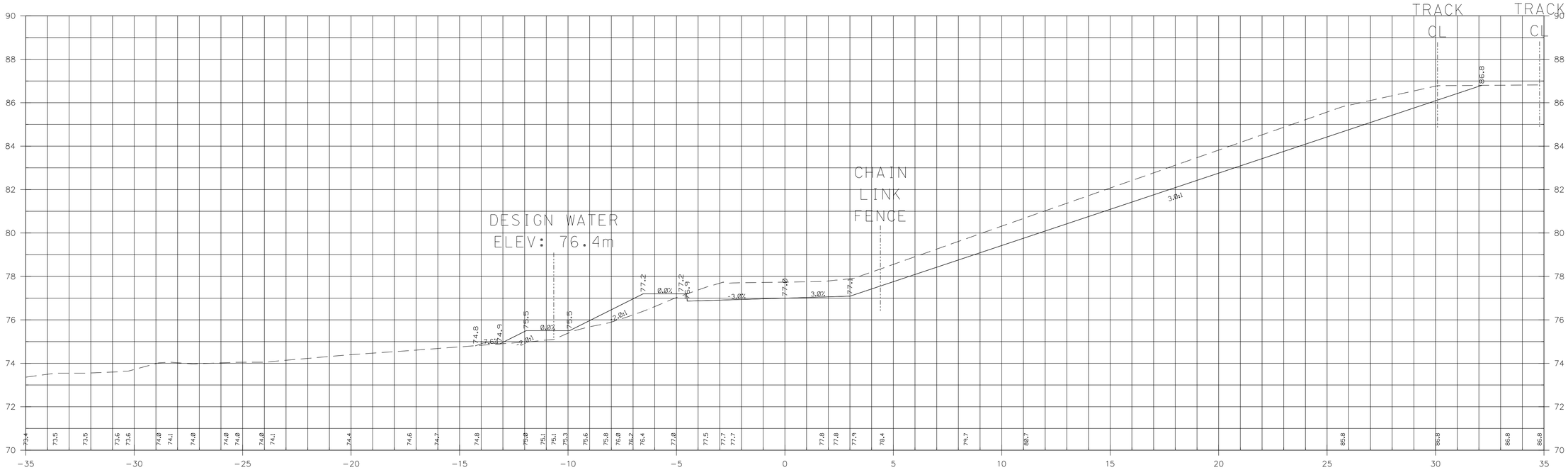

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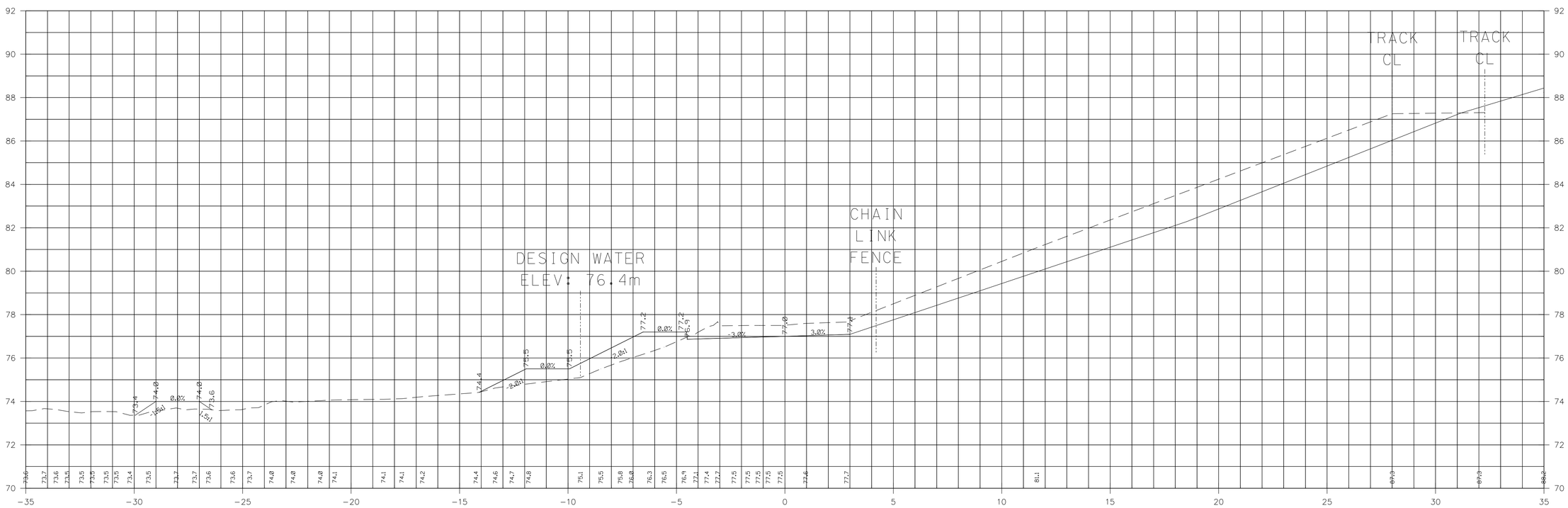

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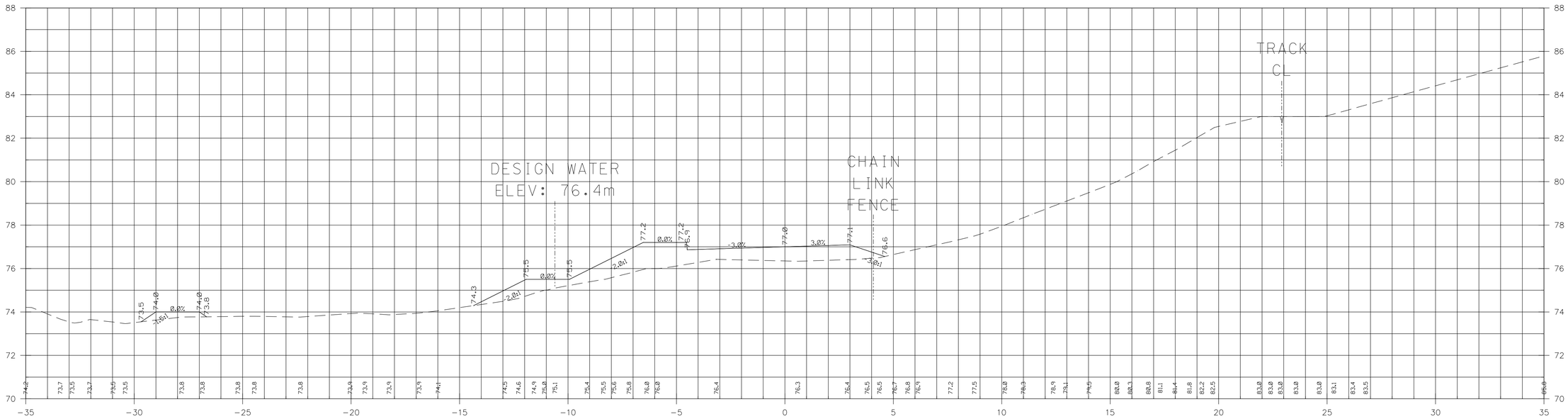

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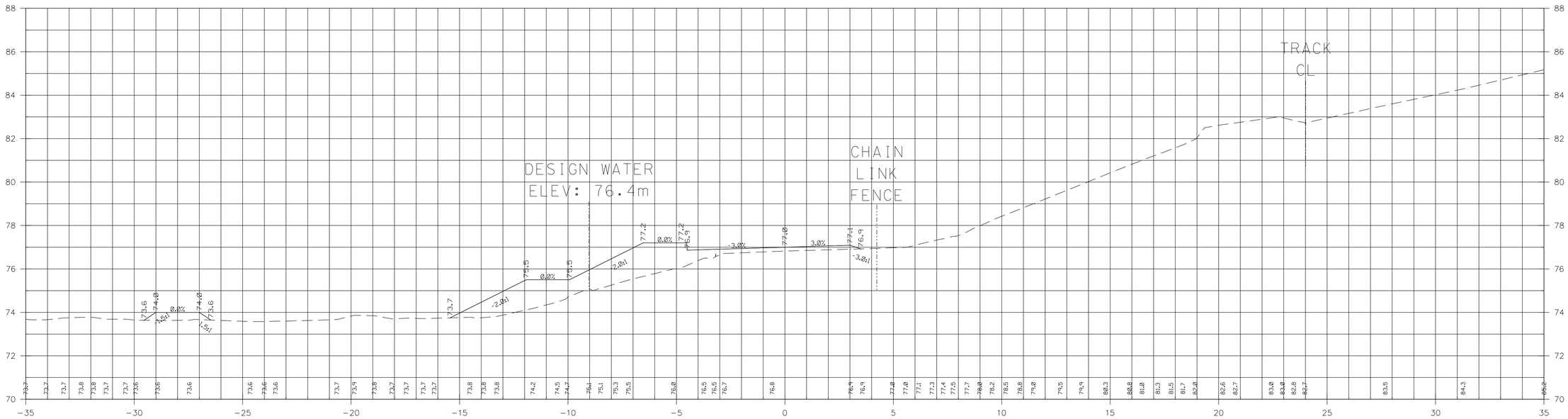

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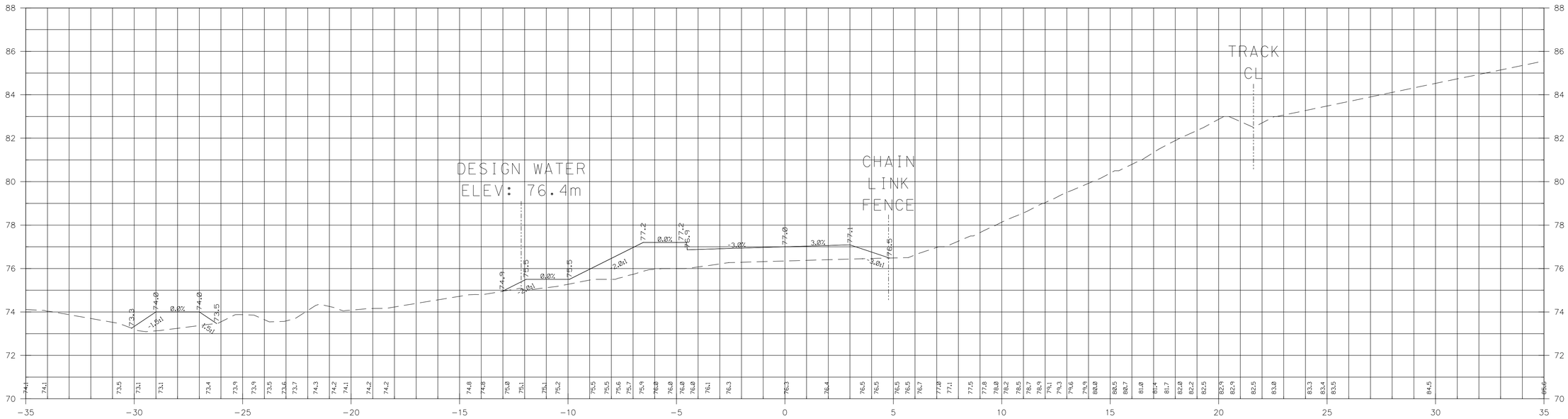

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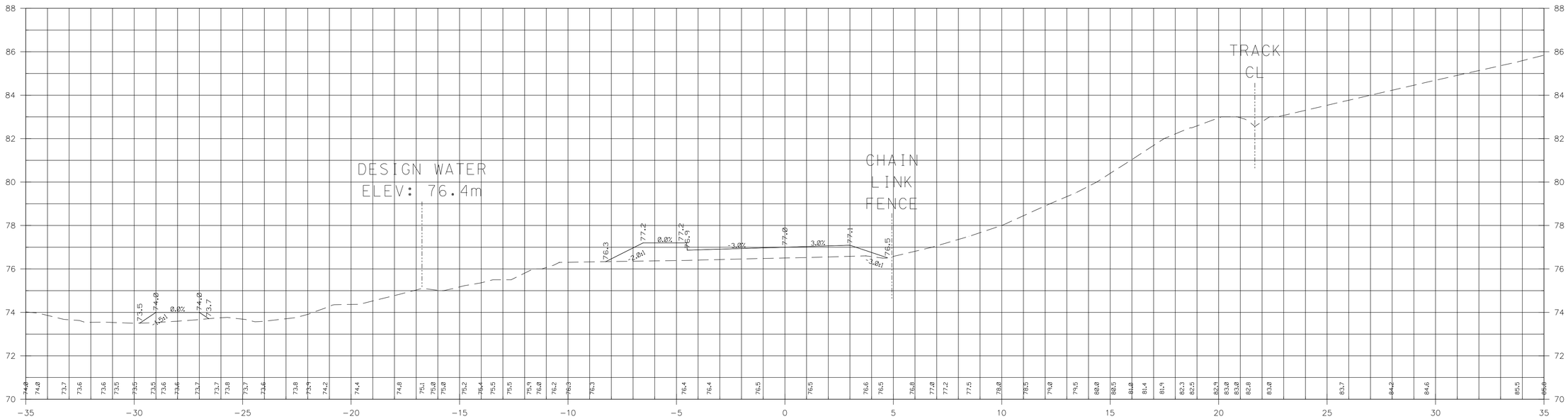

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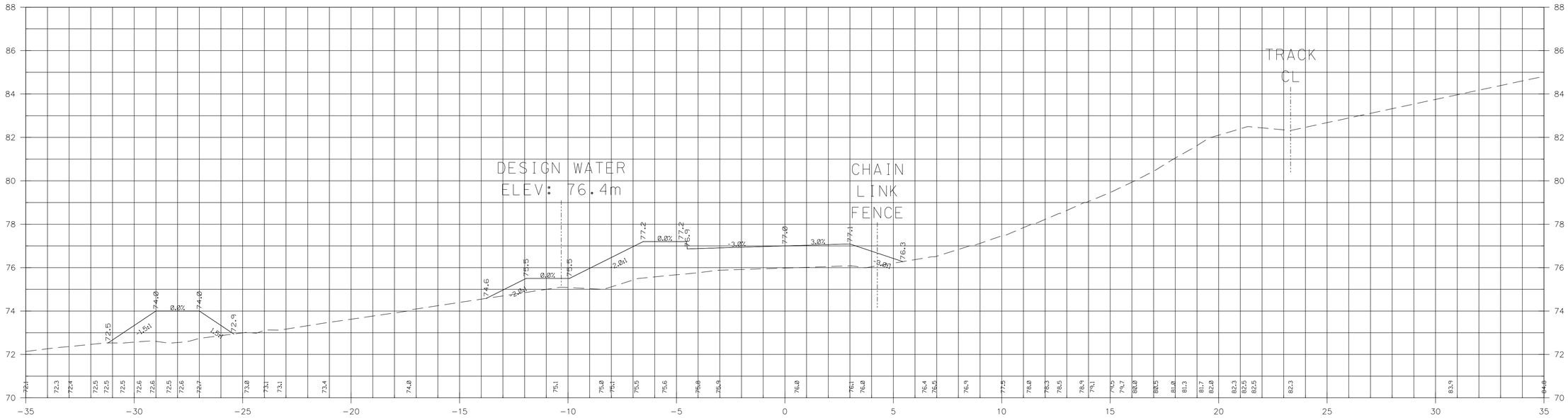

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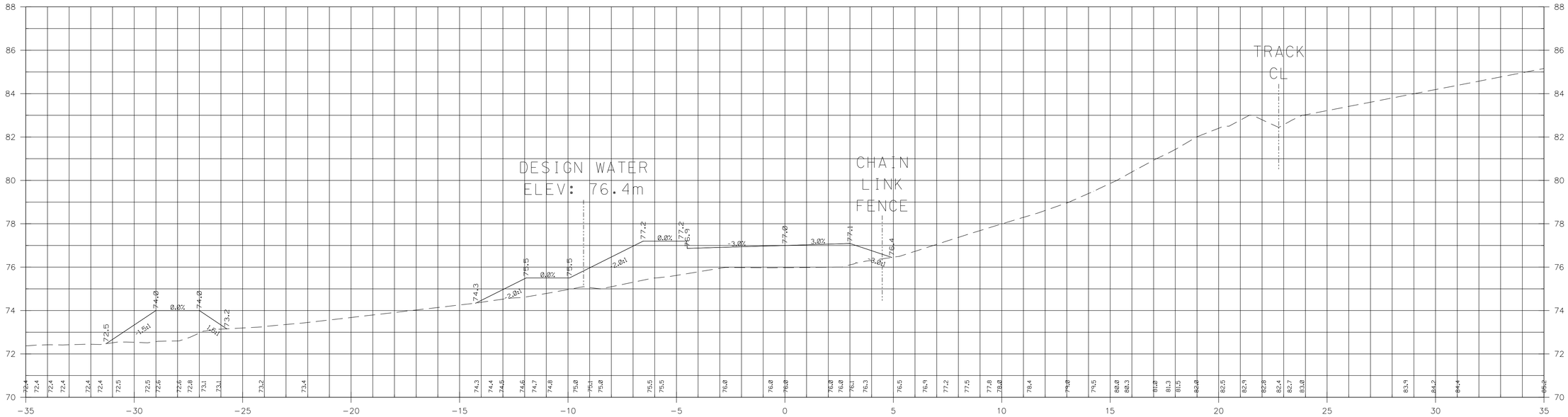

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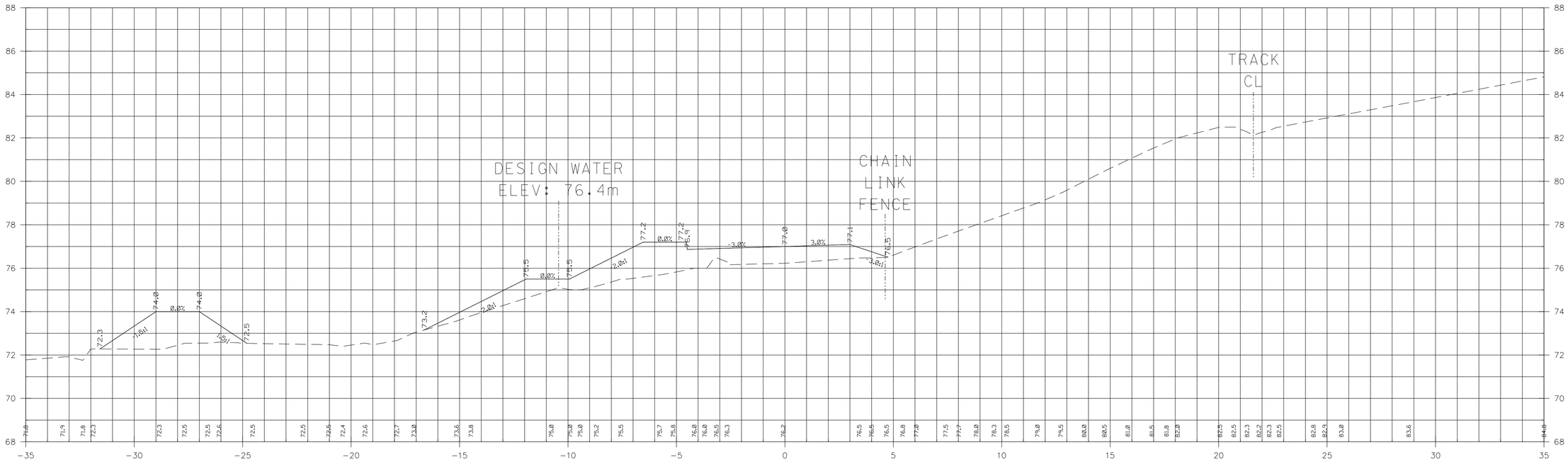

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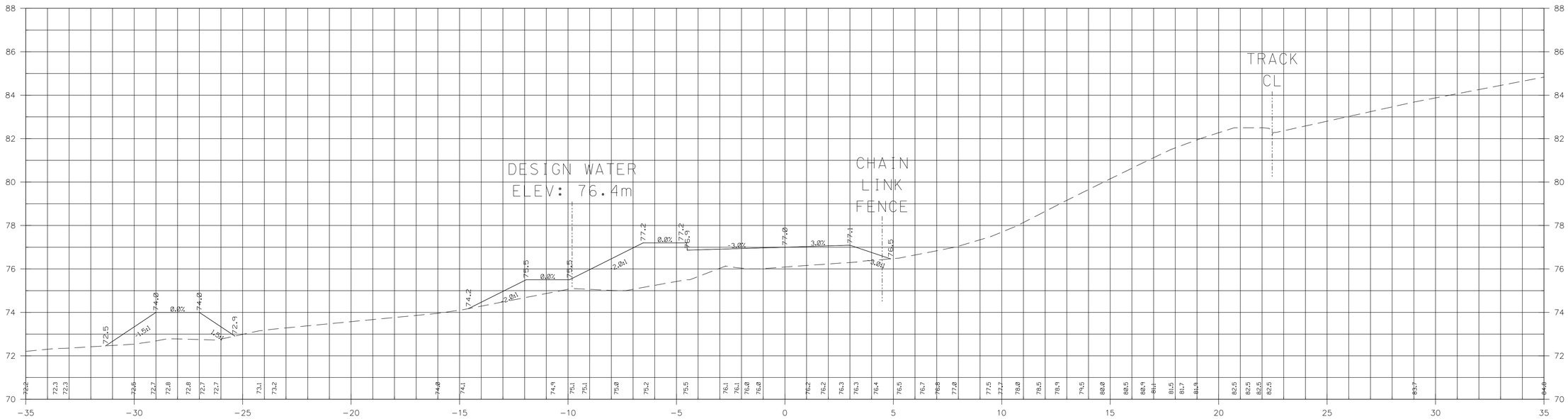

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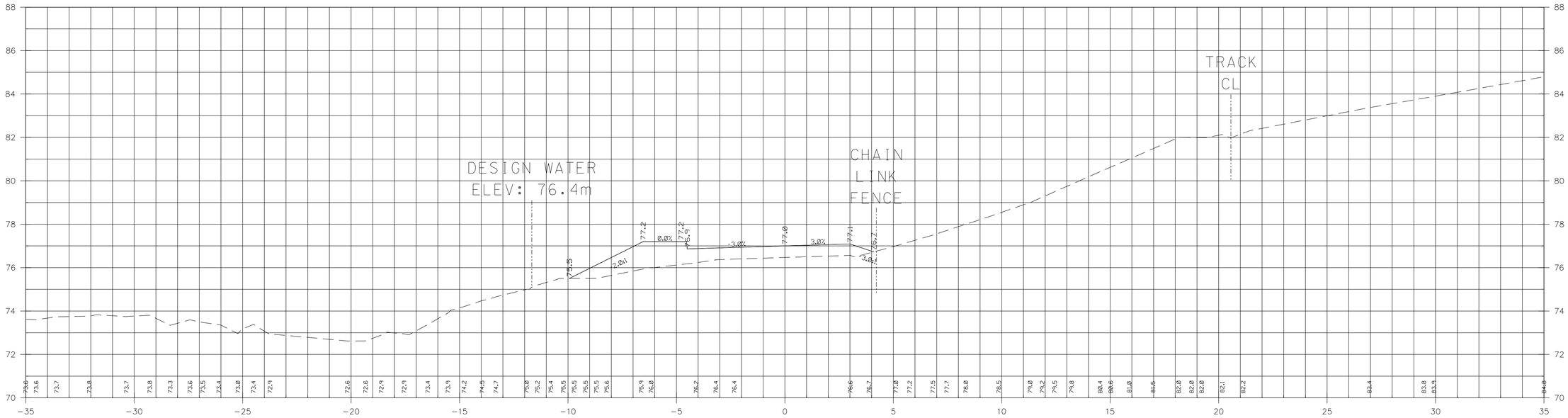
SCALE: 1:100 STA 0+320.00 TO STA 0+340.00



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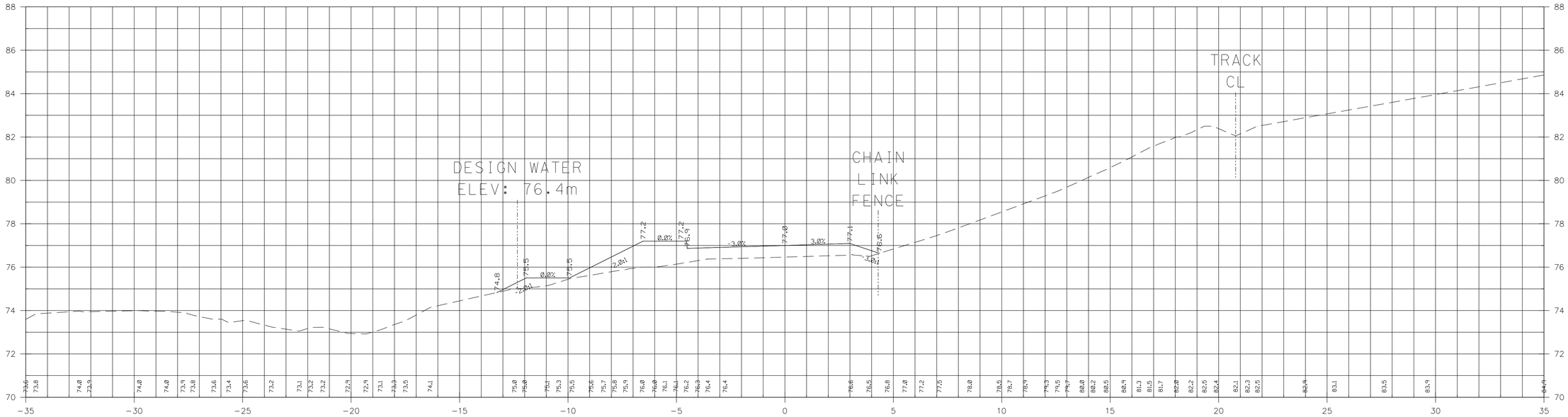

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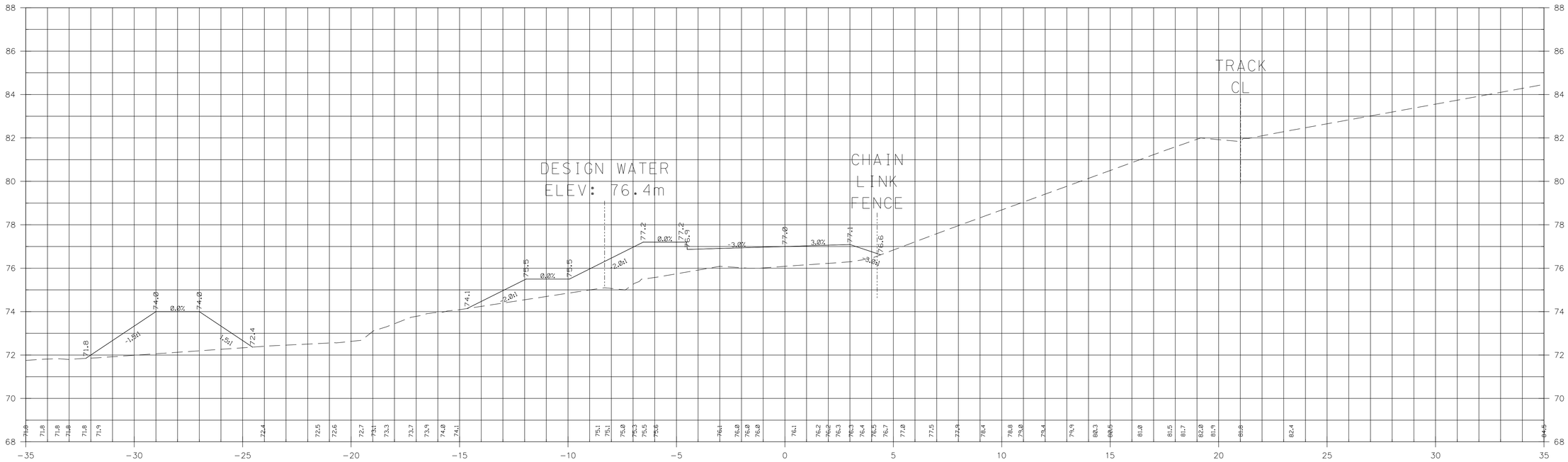

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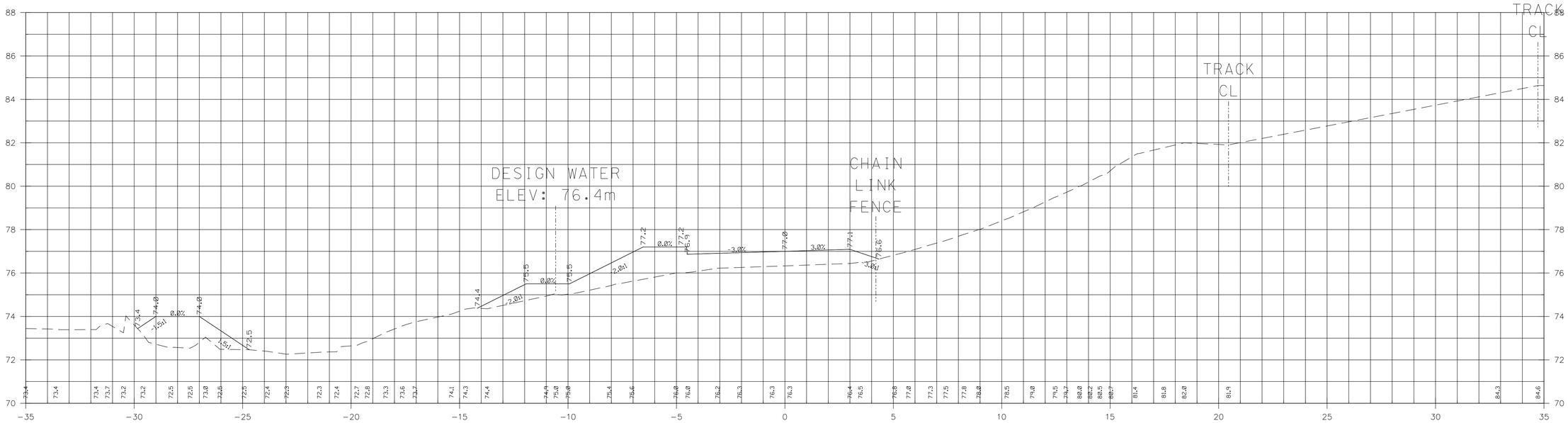

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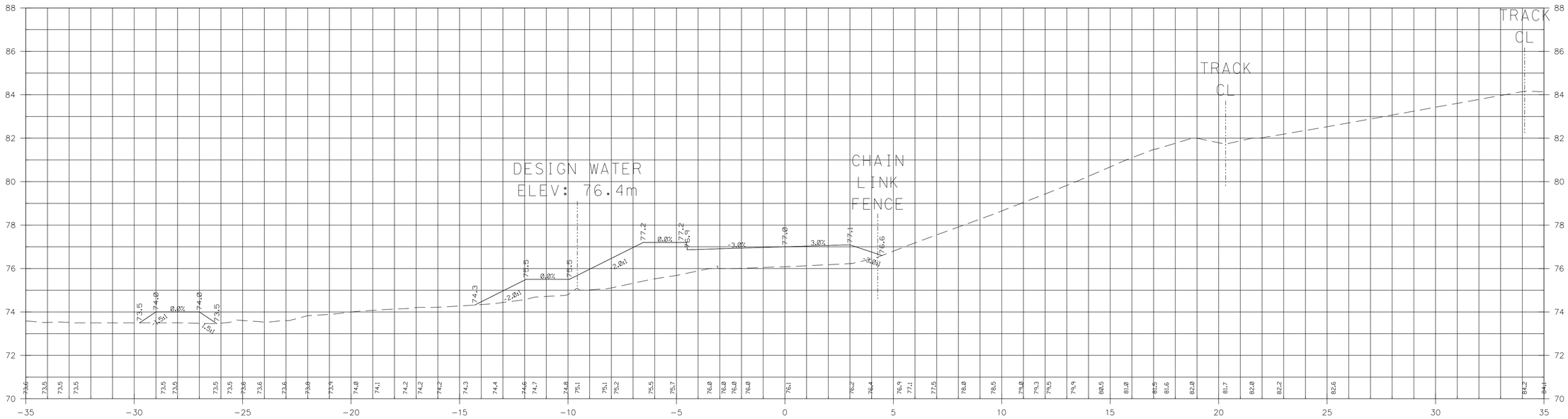

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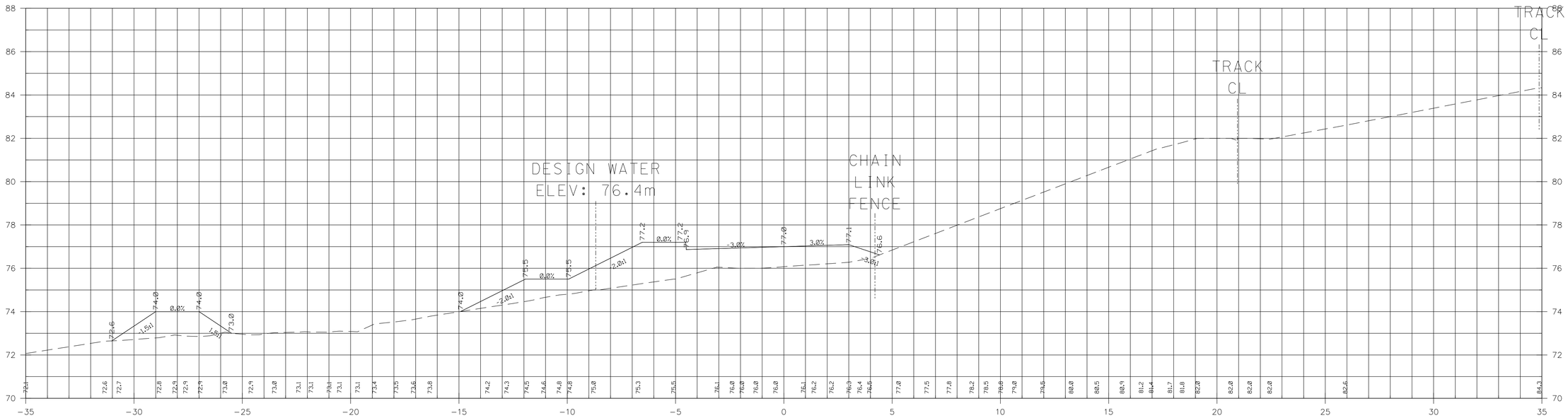

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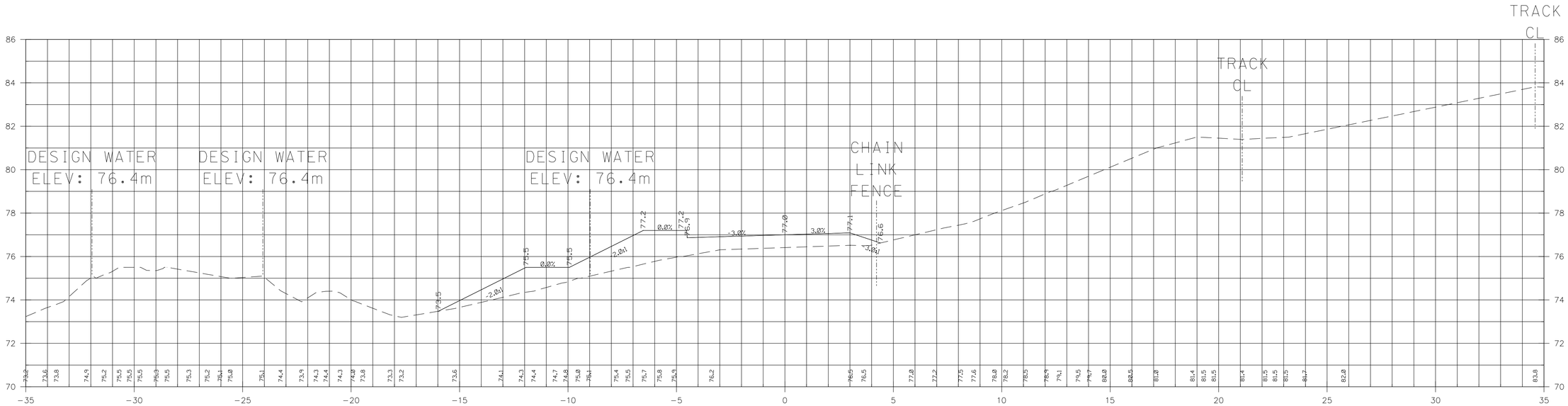

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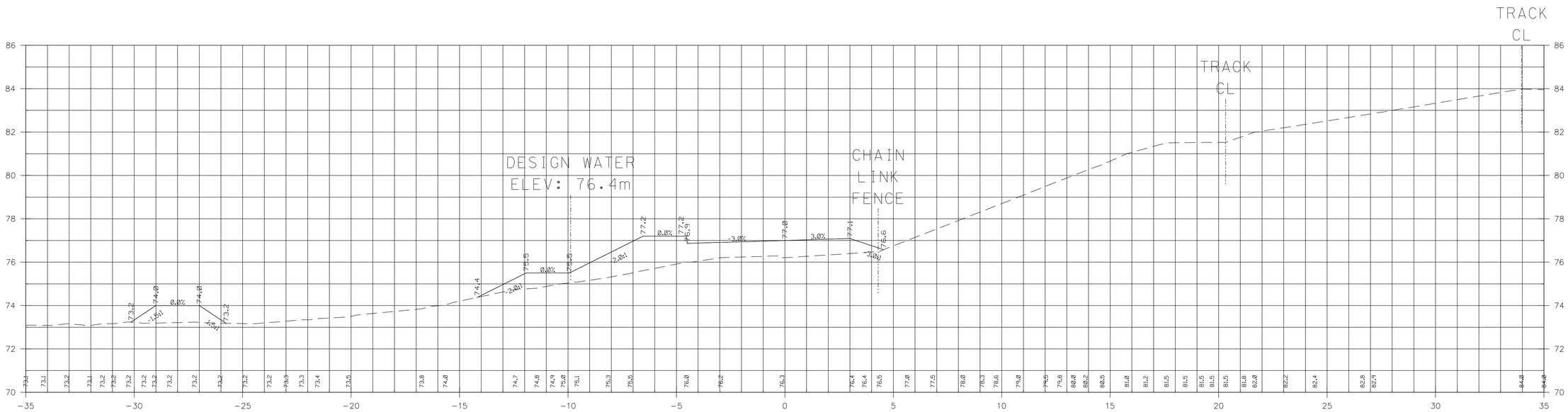

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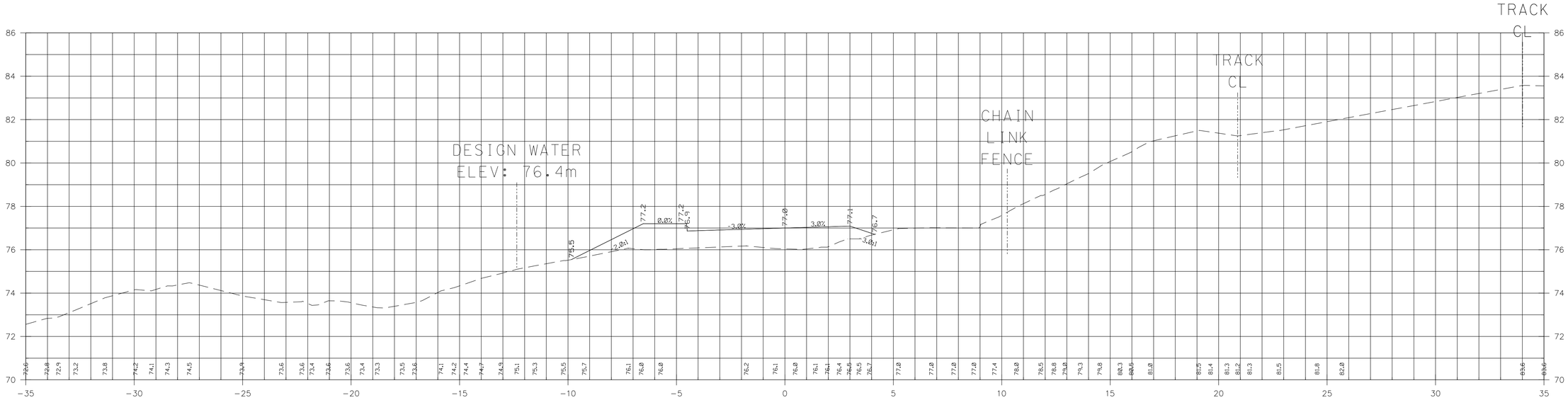

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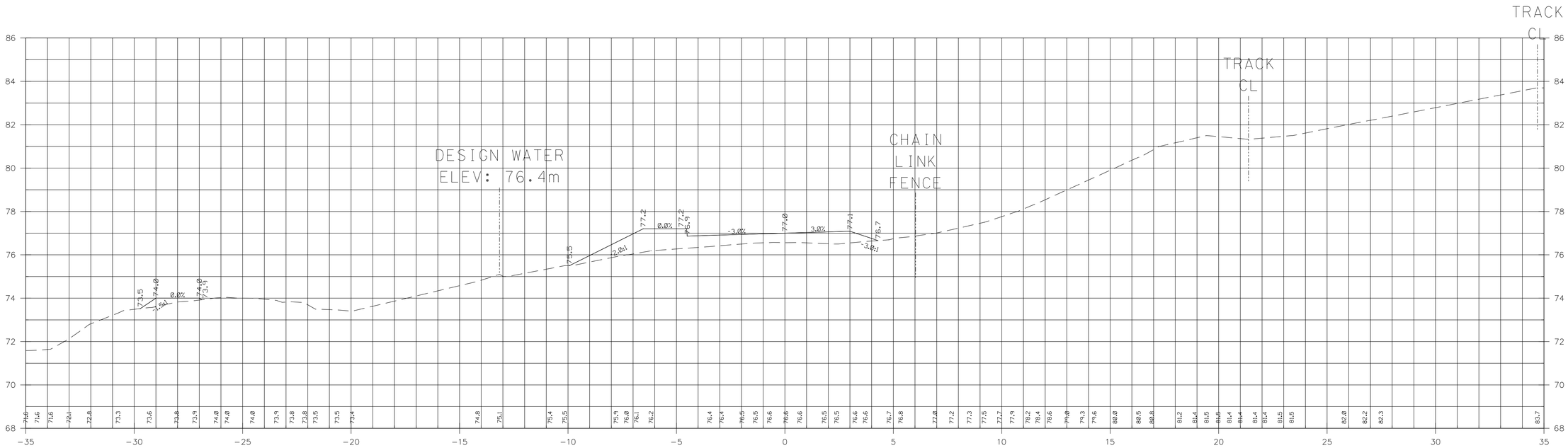

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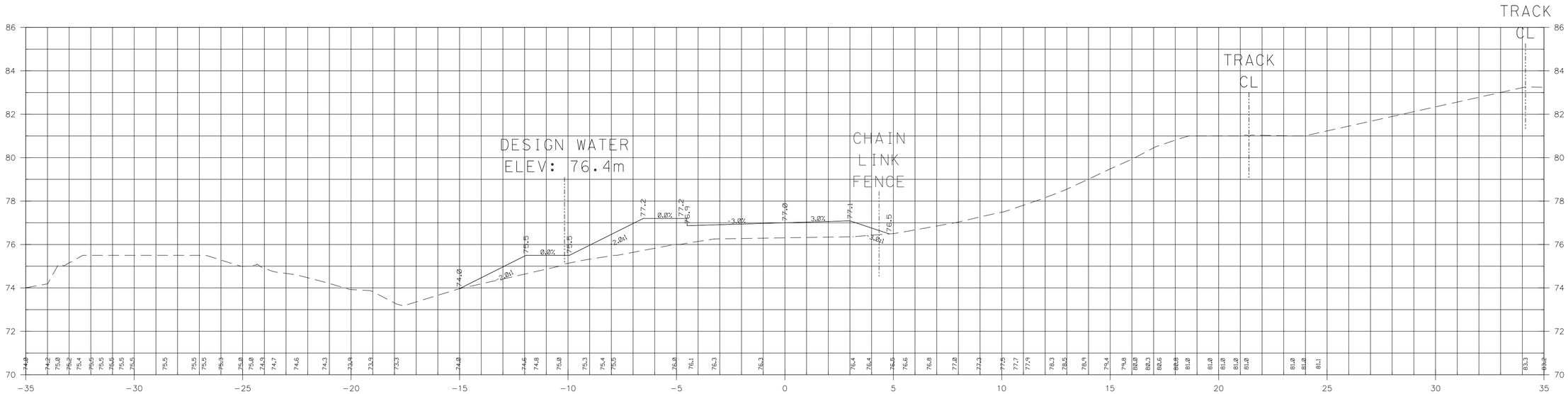

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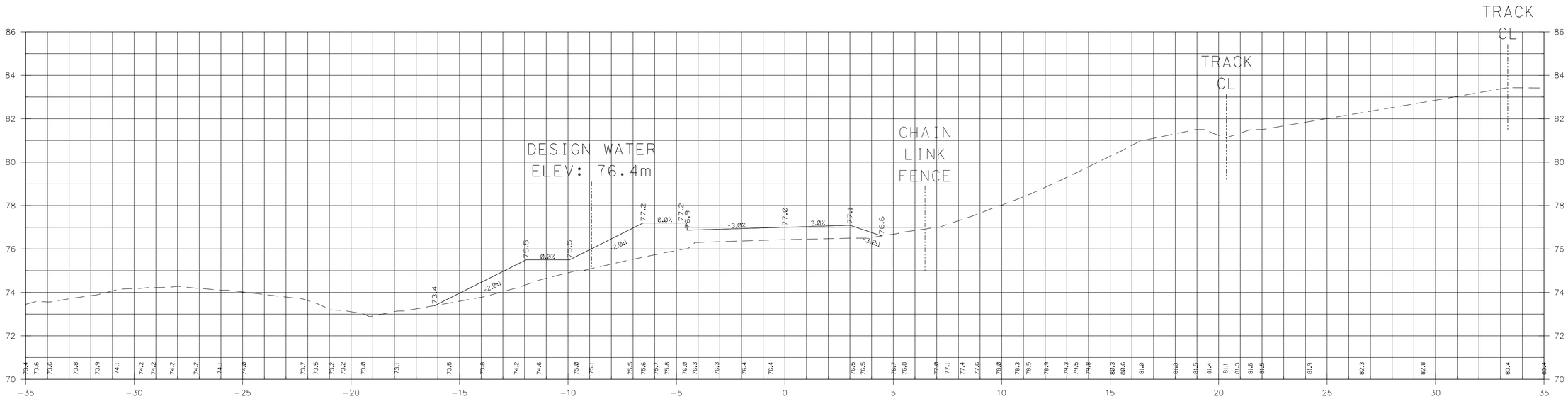

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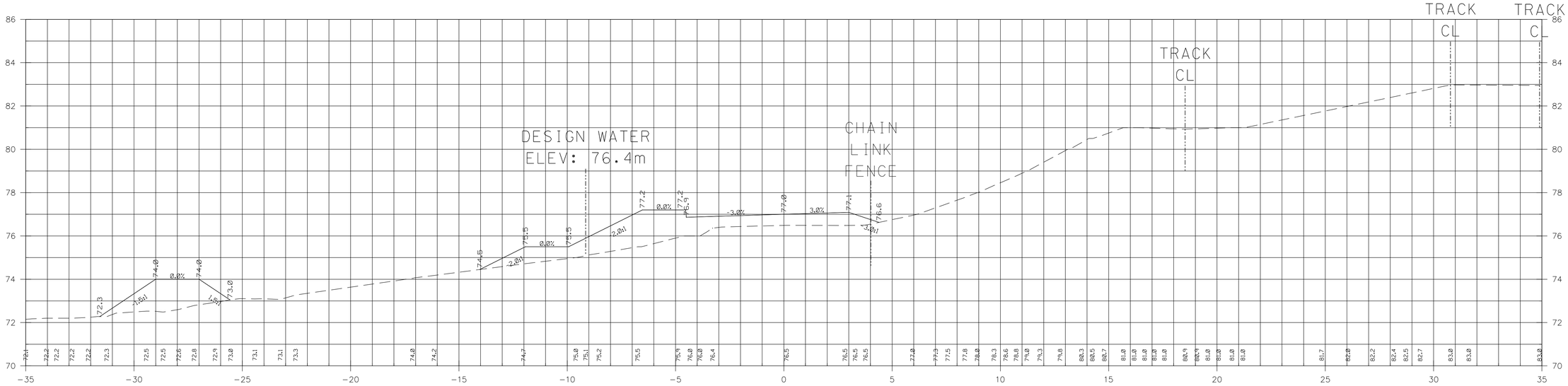

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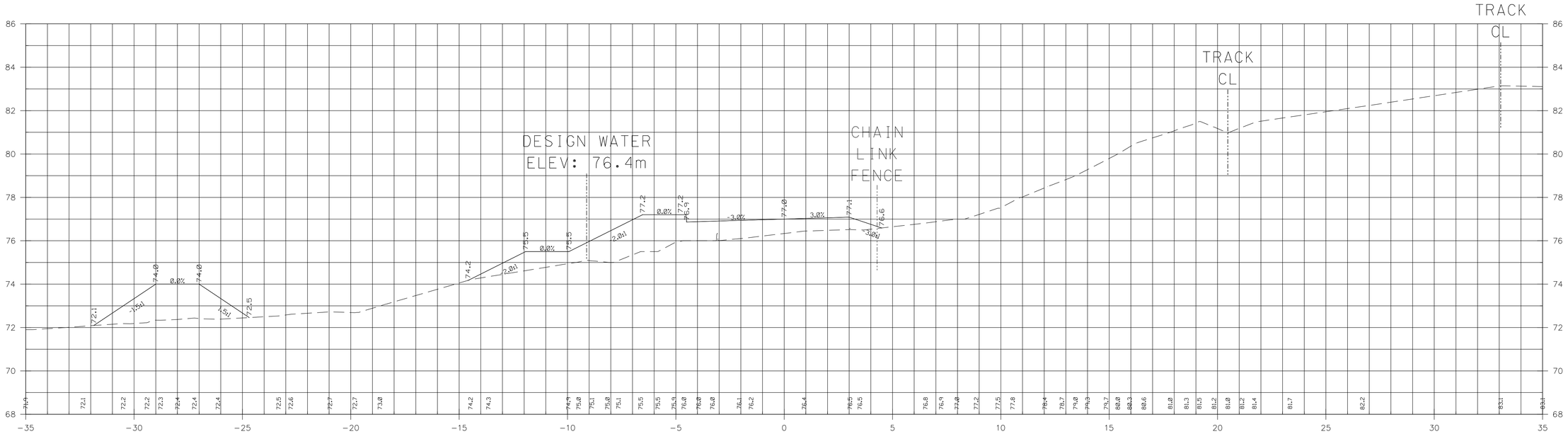

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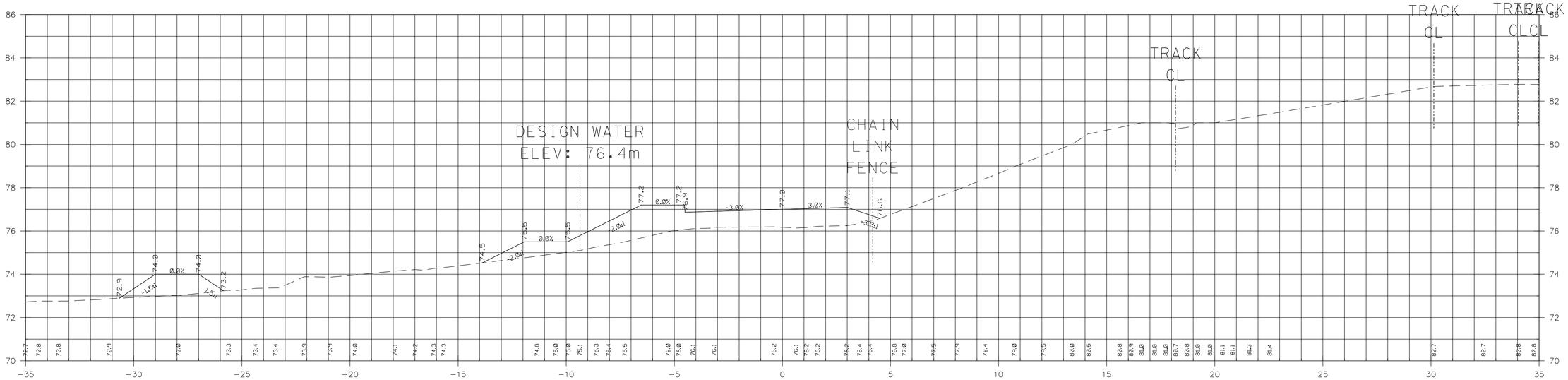

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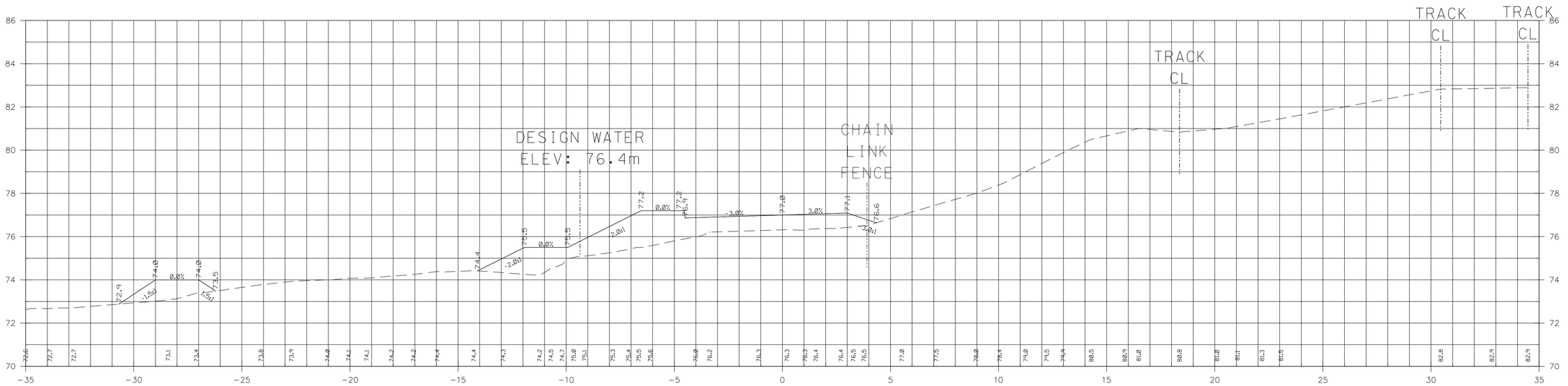

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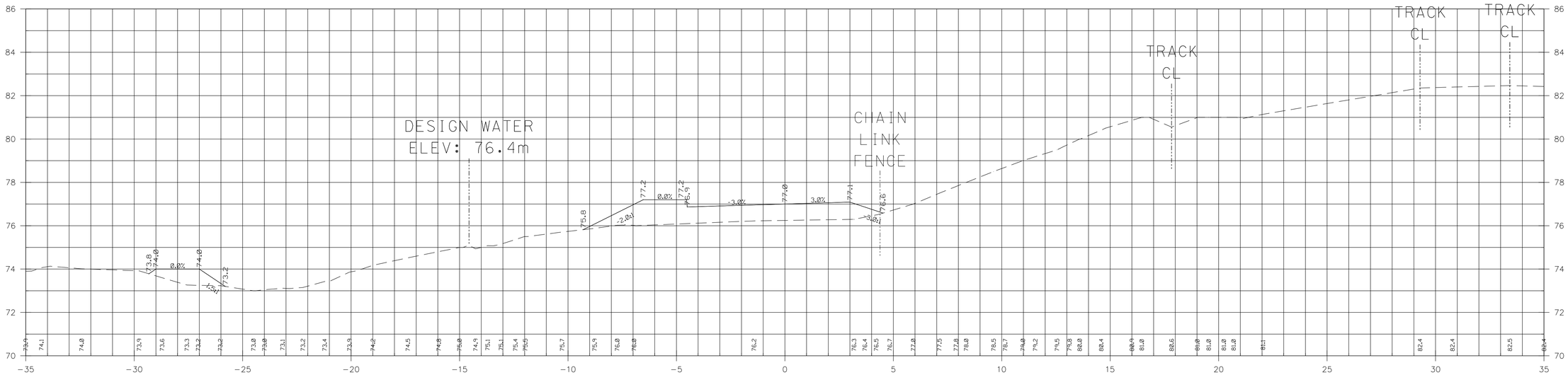

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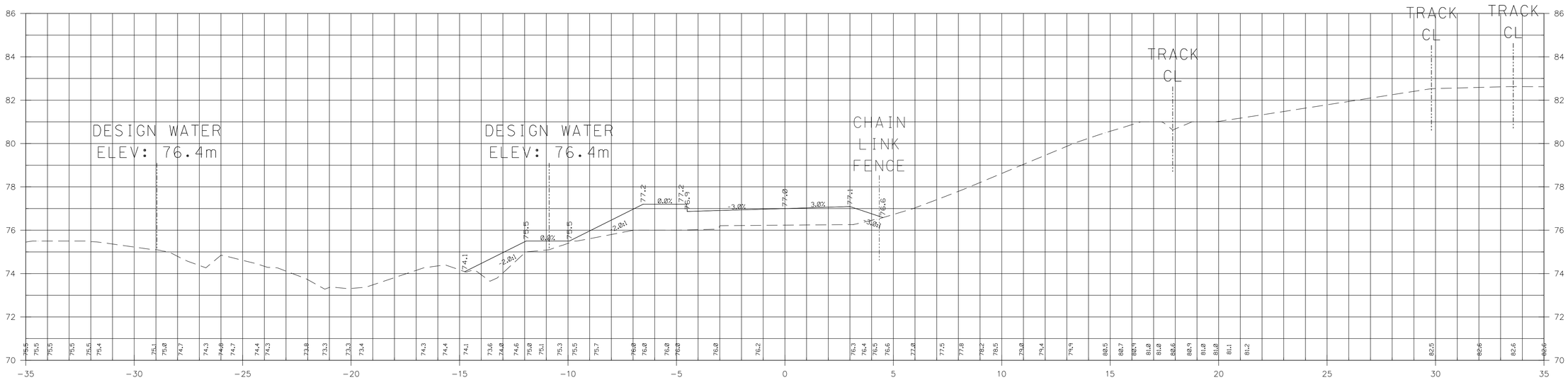

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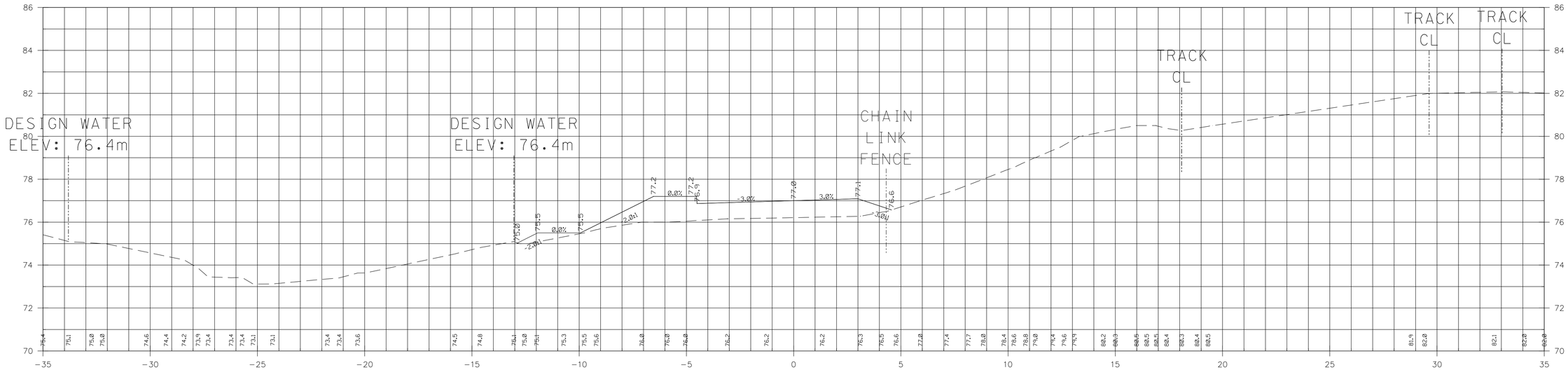

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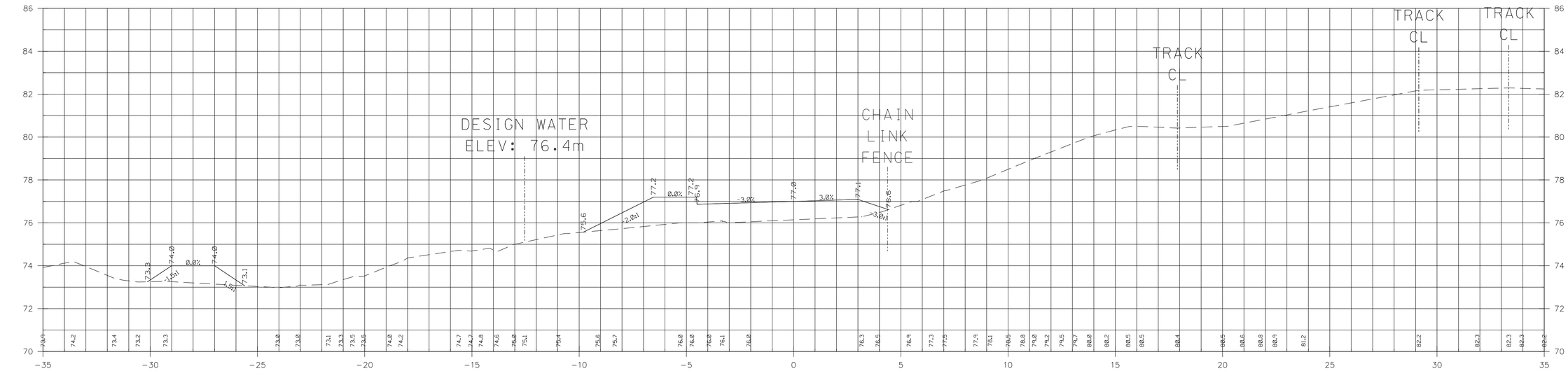

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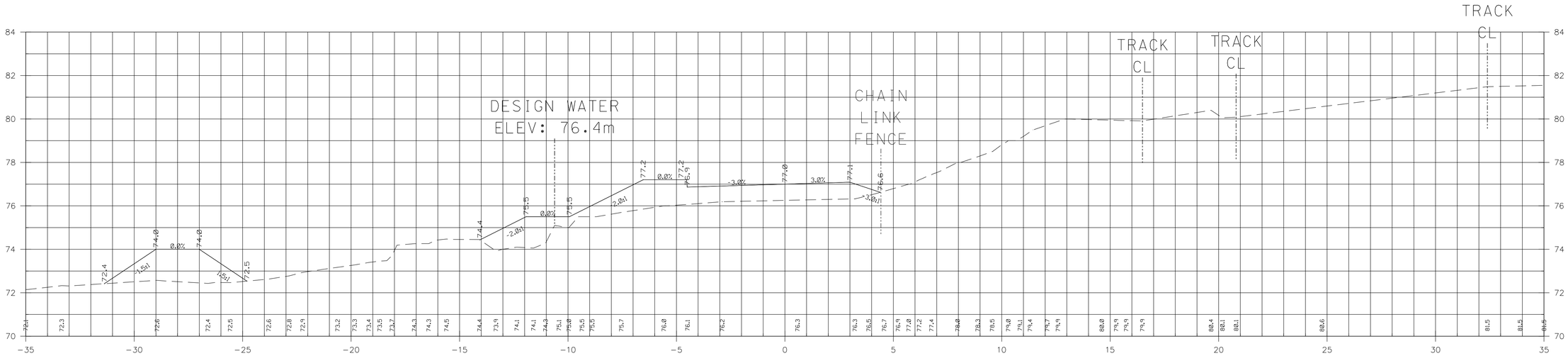

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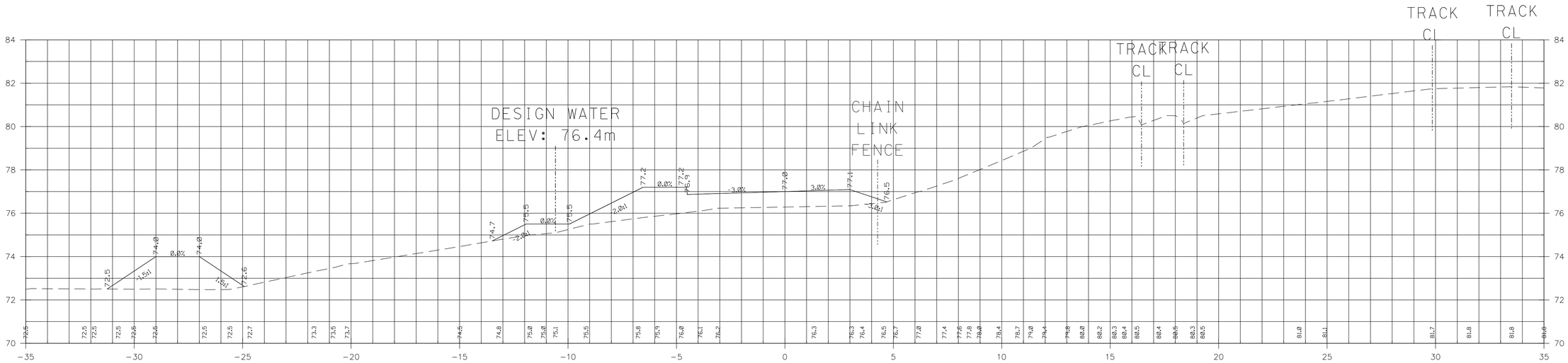

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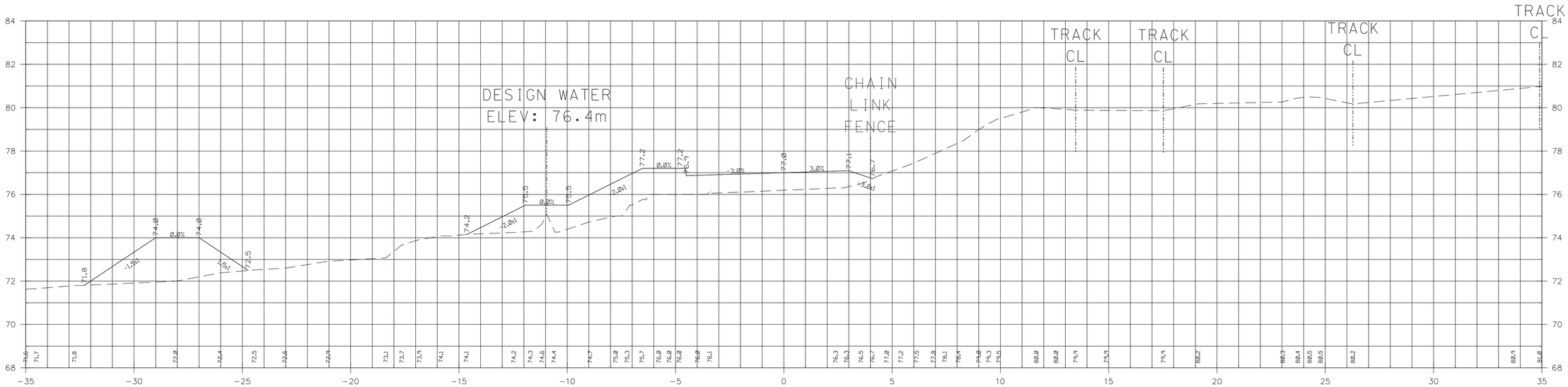

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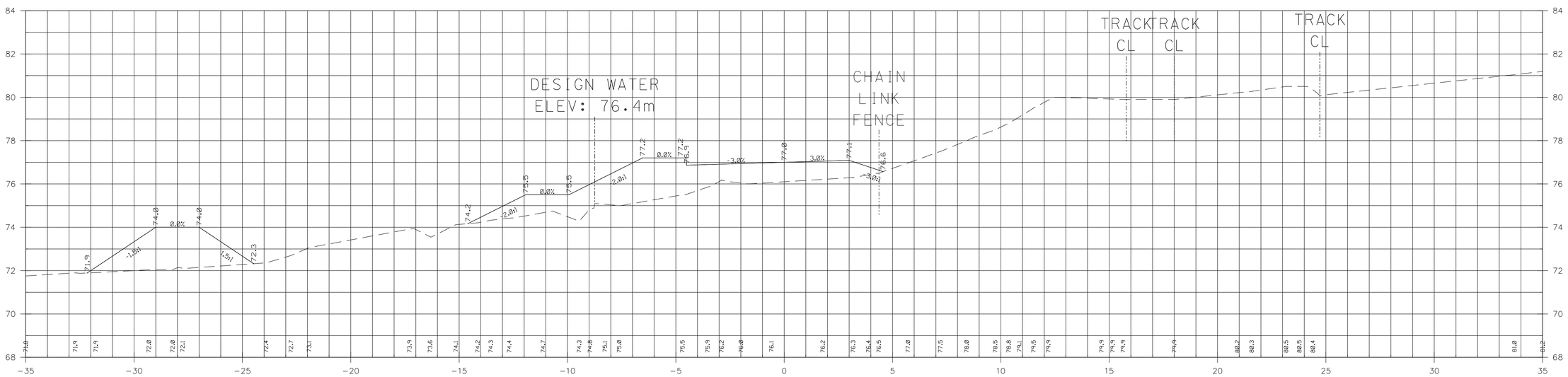

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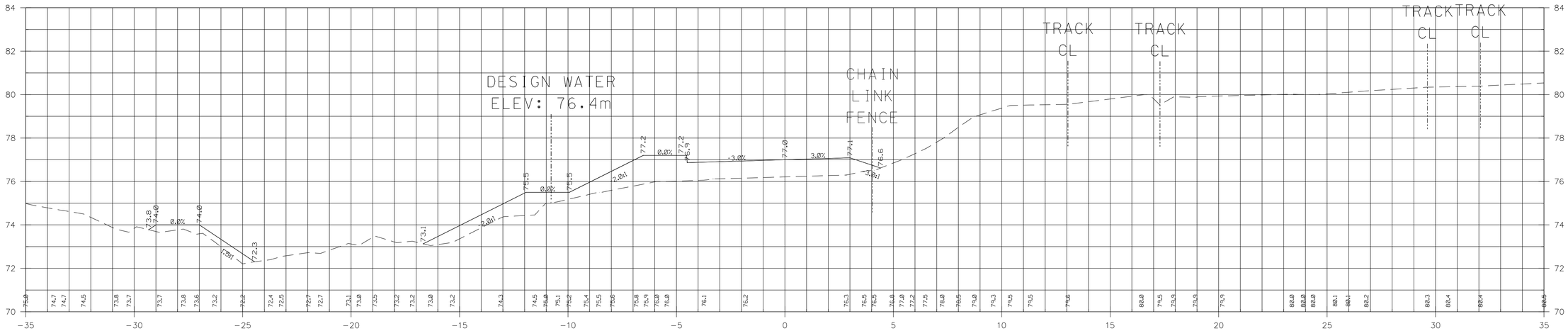

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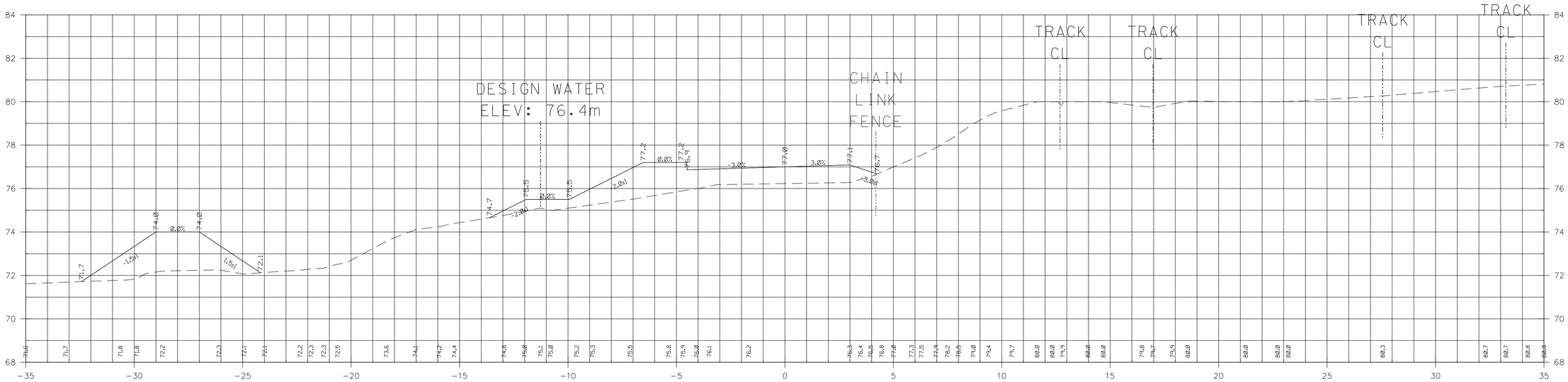

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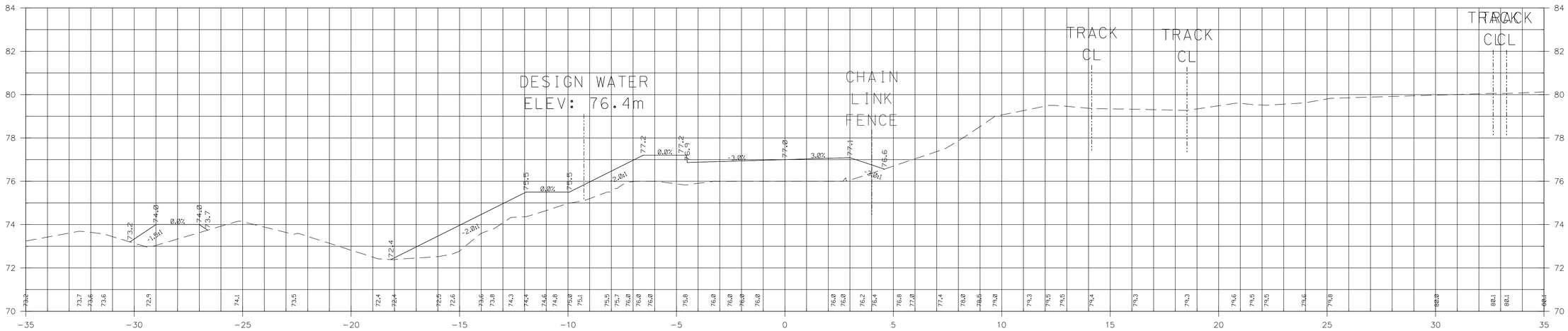
SCALE: 1:100 STA 0+840.00 TO STA 0+860.00



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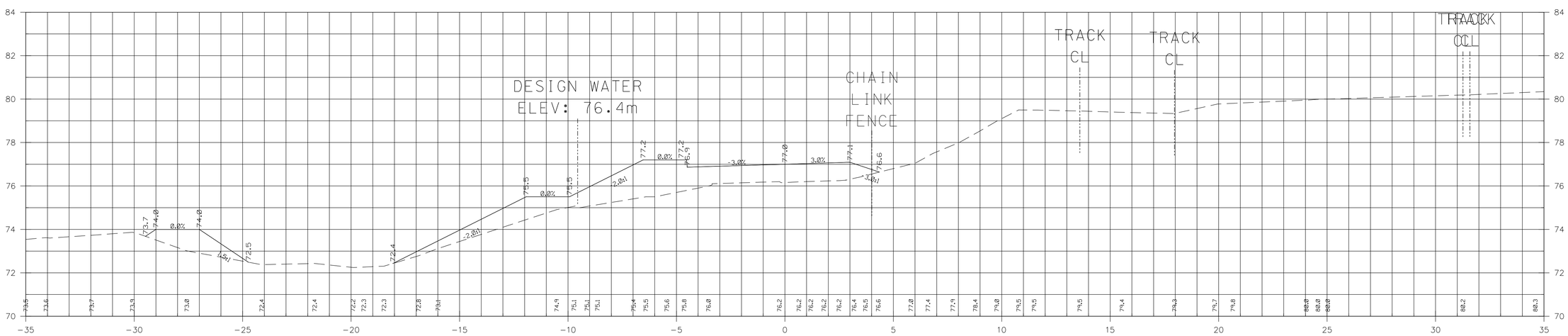

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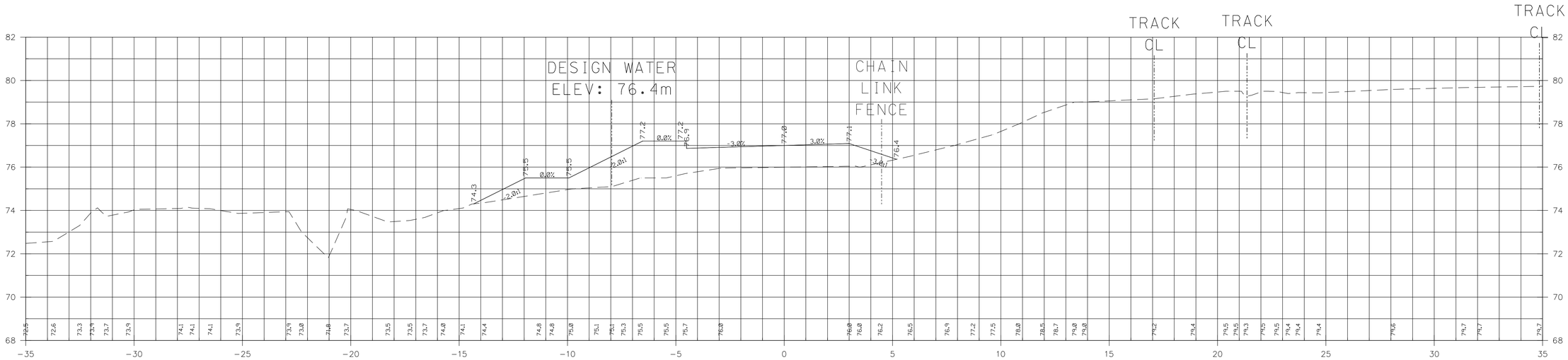
SCALE: 1:100 STA 0+880.00 TO STA 0+900.00



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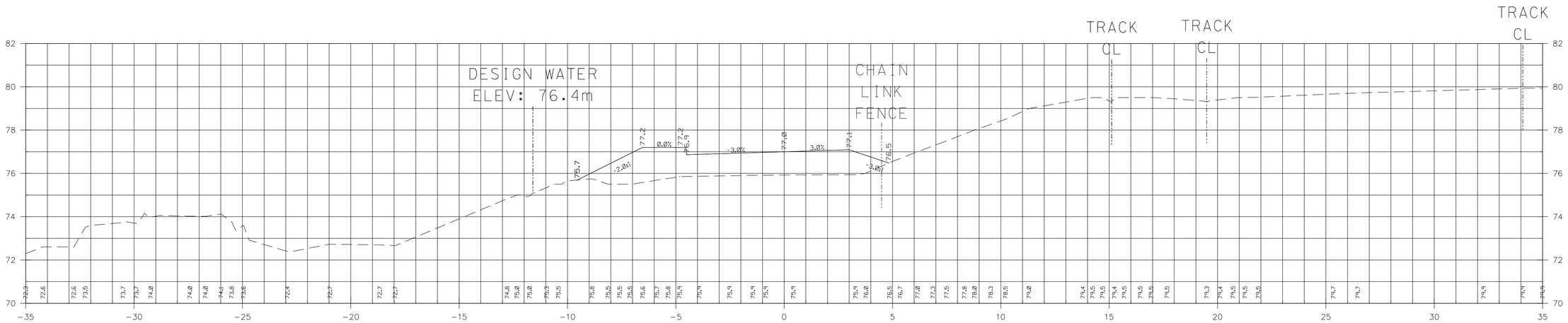

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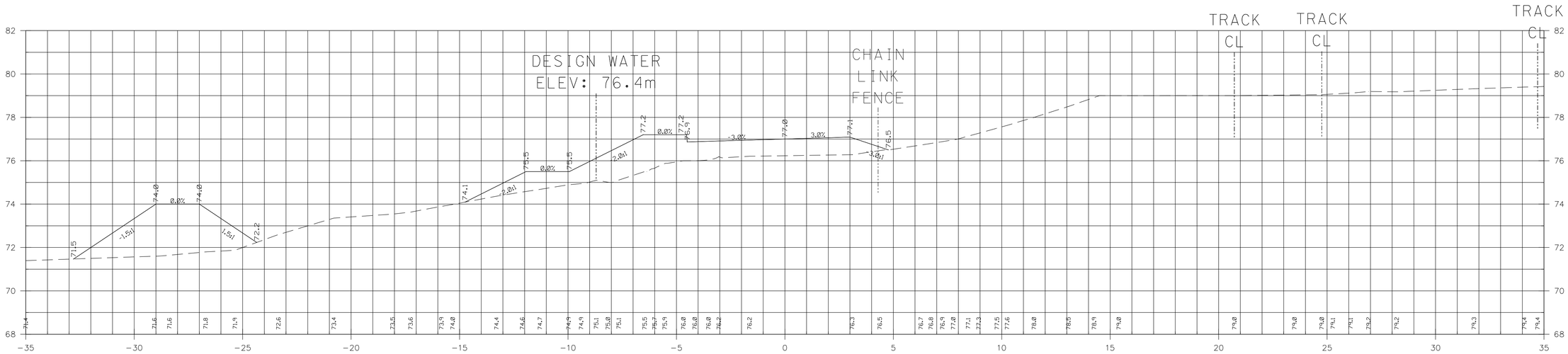
SCALE: 1:100 STA 0+920.00 TO STA 0+940.00



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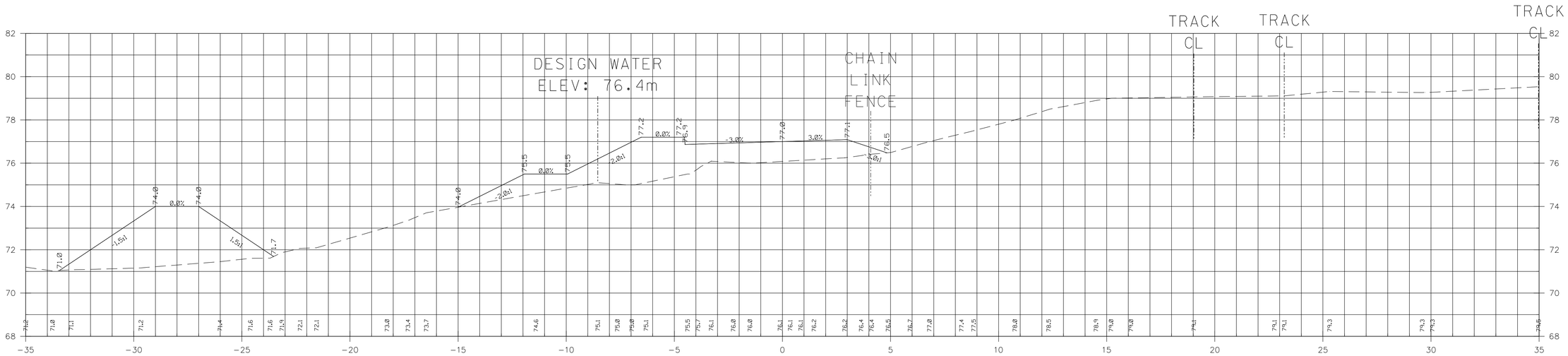

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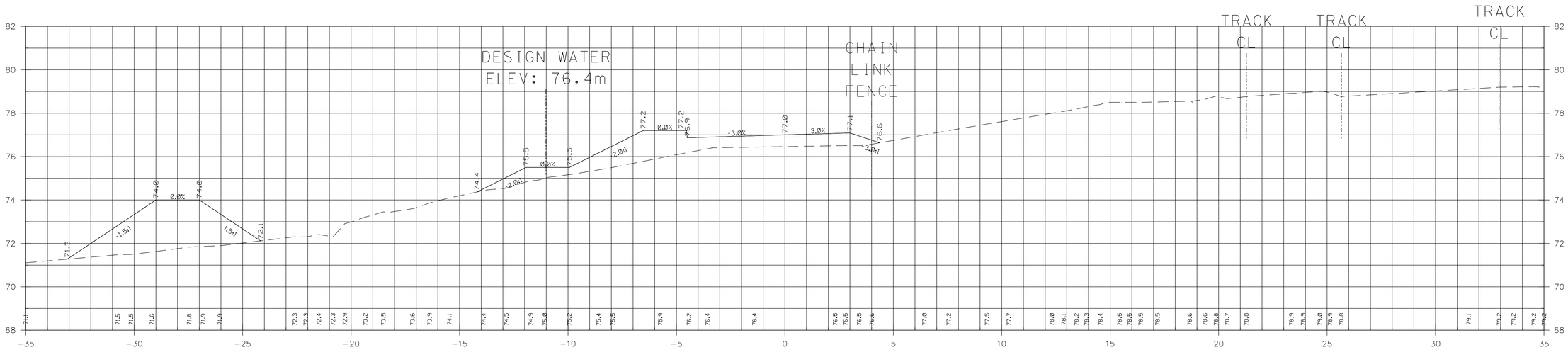
SCALE: 1:100 STA 0+960.00 TO STA 0+980.00



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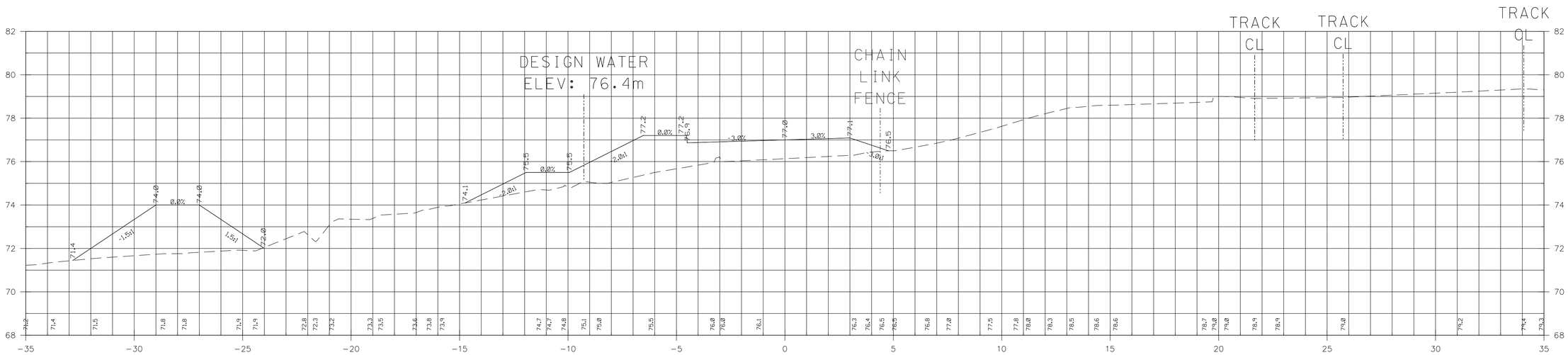
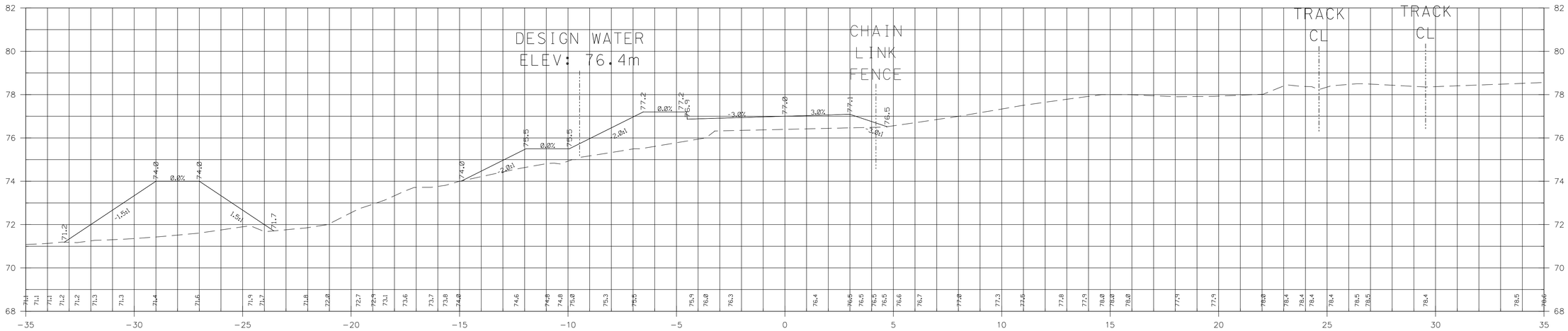
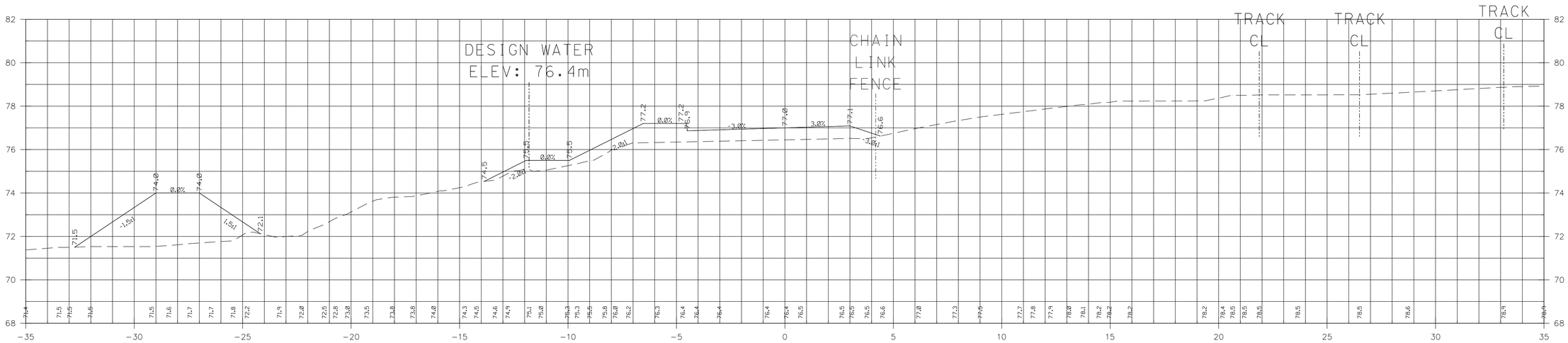


0+960.00

SCALE: 1:100 STA 1+000.00 TO STA 1+020.00

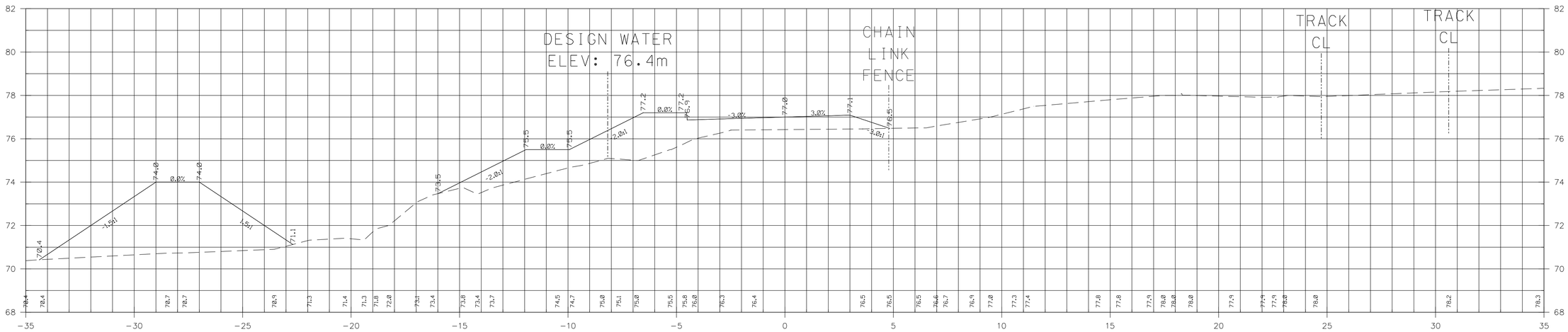


1+020.00

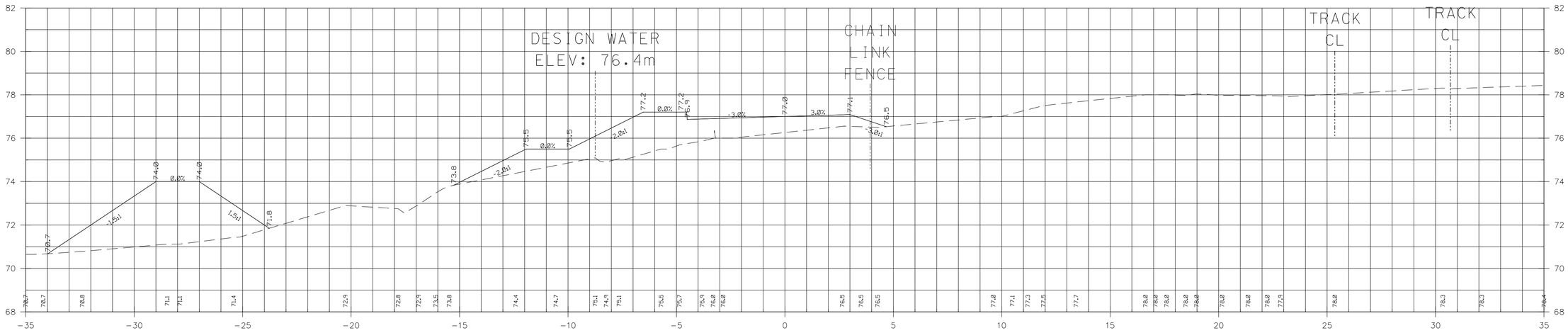


1+000.00

SCALE: 1:100 STA 1+040.00 TO STA 1+060.00

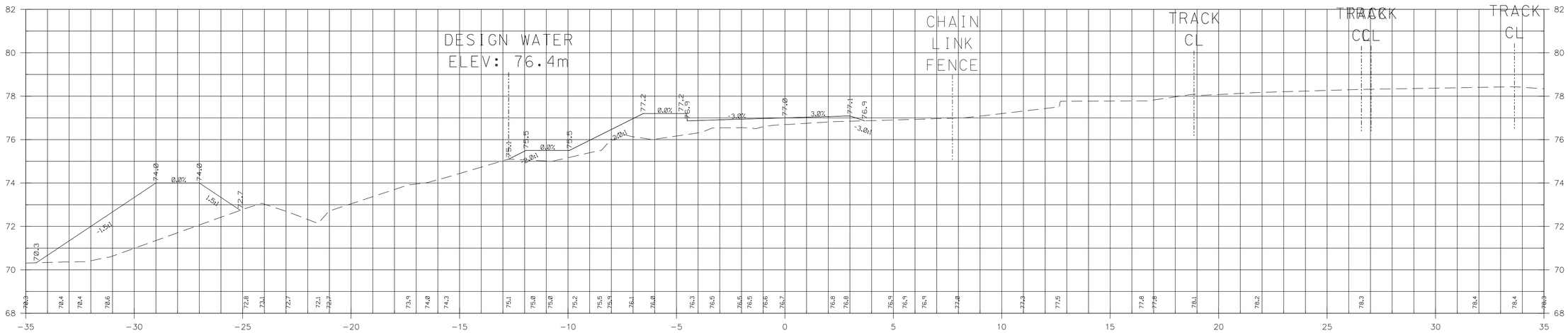


1+060.00

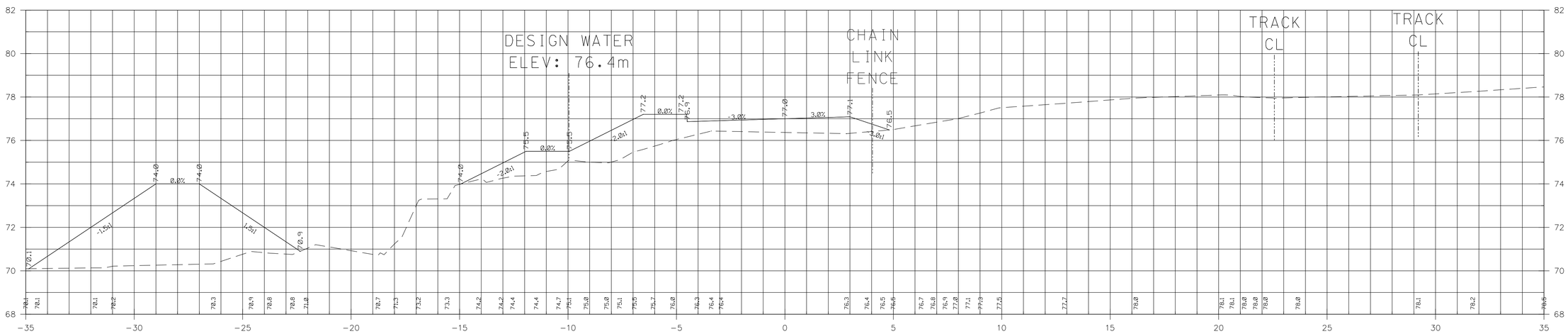


1+040.00

SCALE: 1:100 STA 1+080.00 TO STA 1+100.00

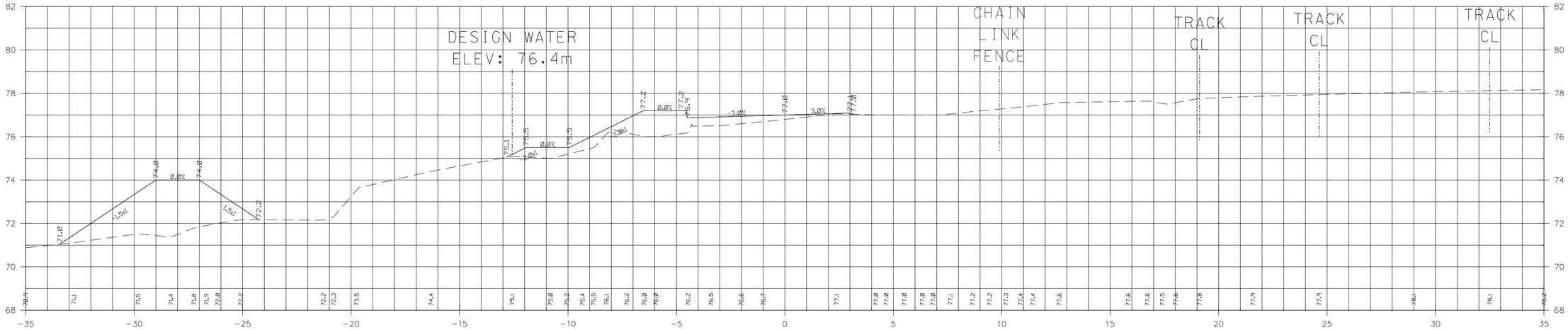


1+100.00

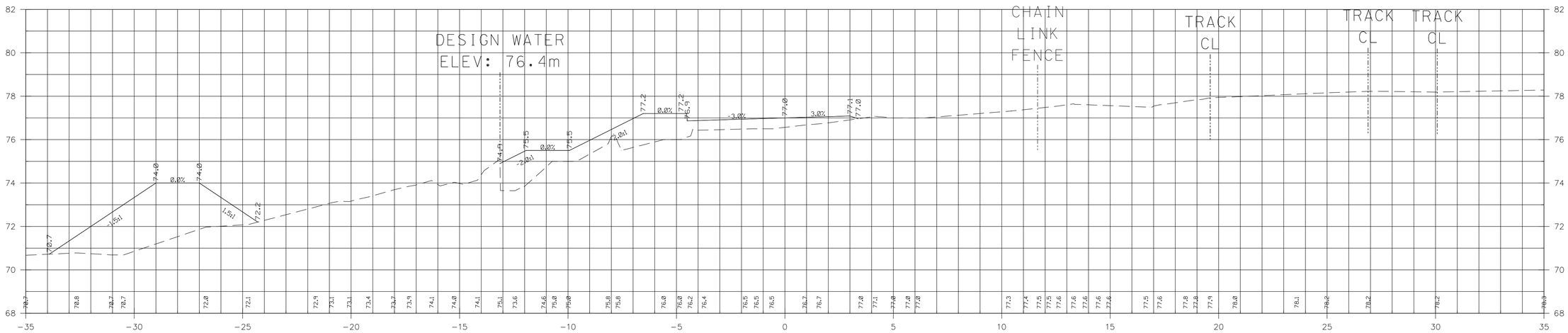


1+080.00

SCALE: 1:100 STA 1+120.00 TO STA 1+140.00

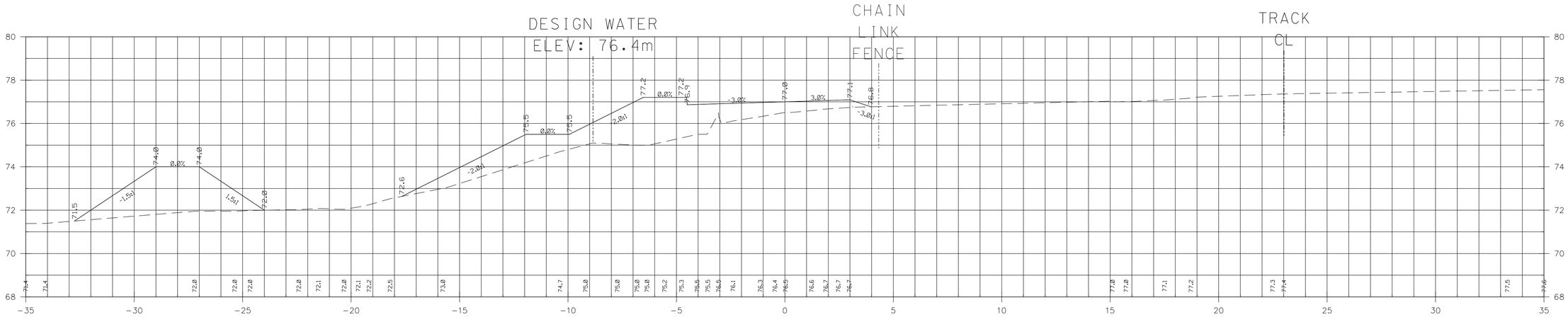


1+140.00

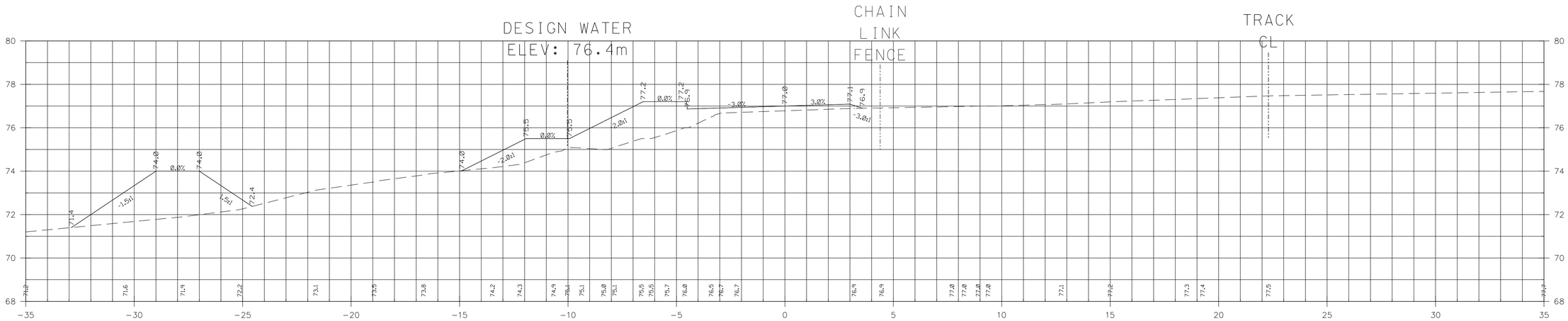


1+120.00

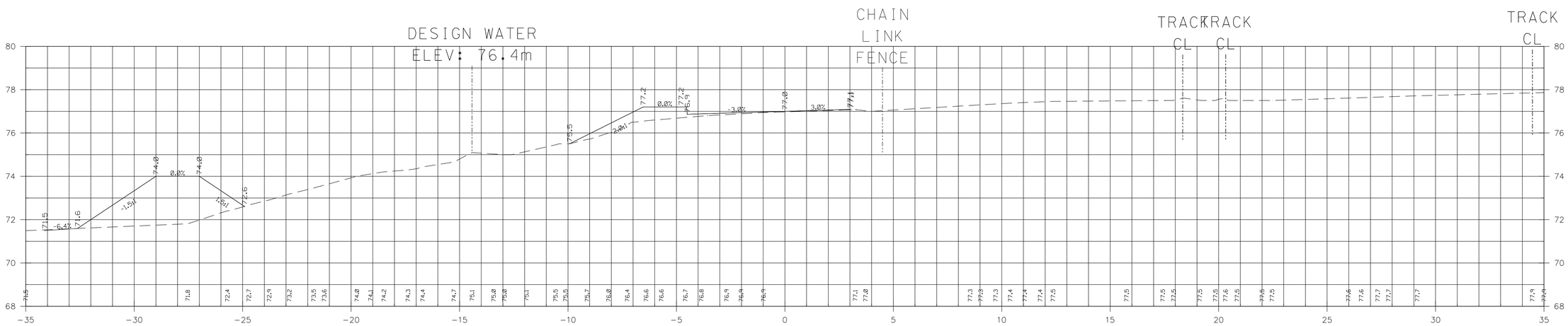
SCALE: 1:100 STA 1+160.00 TO STA 1+200.00



1+200.00

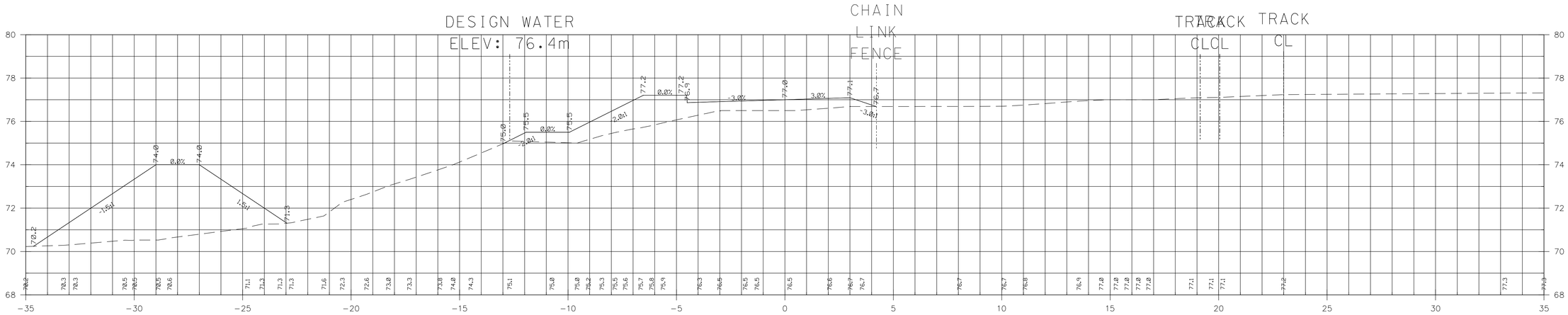


1+180.00

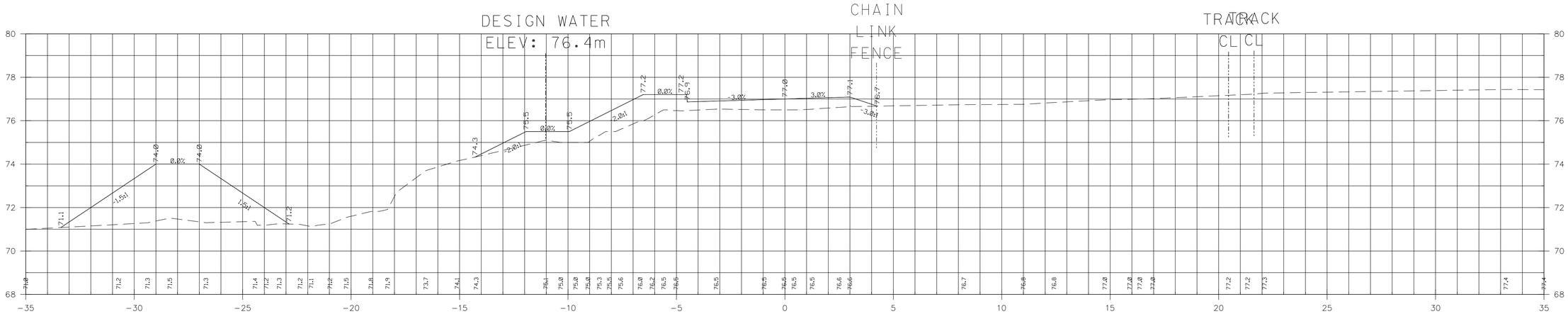


1+160.00

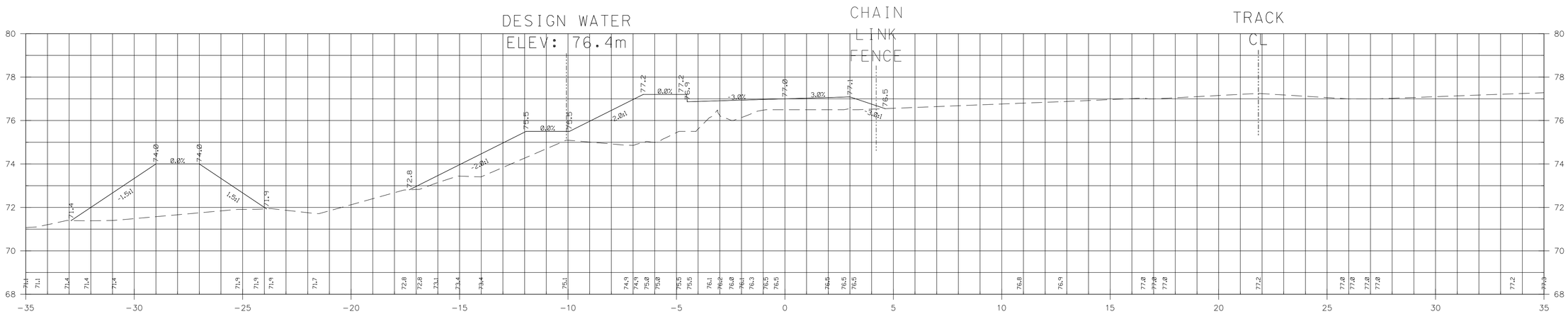
SCALE: 1:100 STA 1+220.00 TO STA 1+260.00



1+260.00

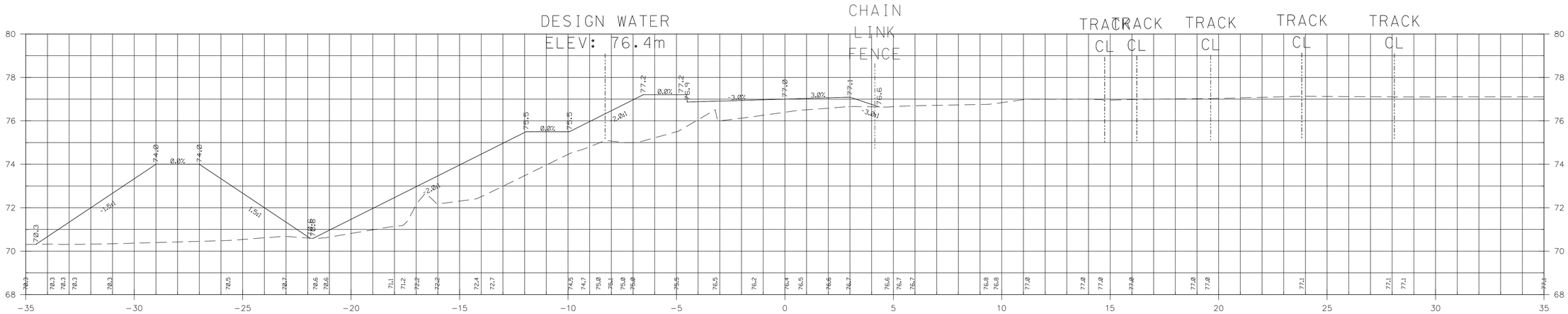


1+240.00

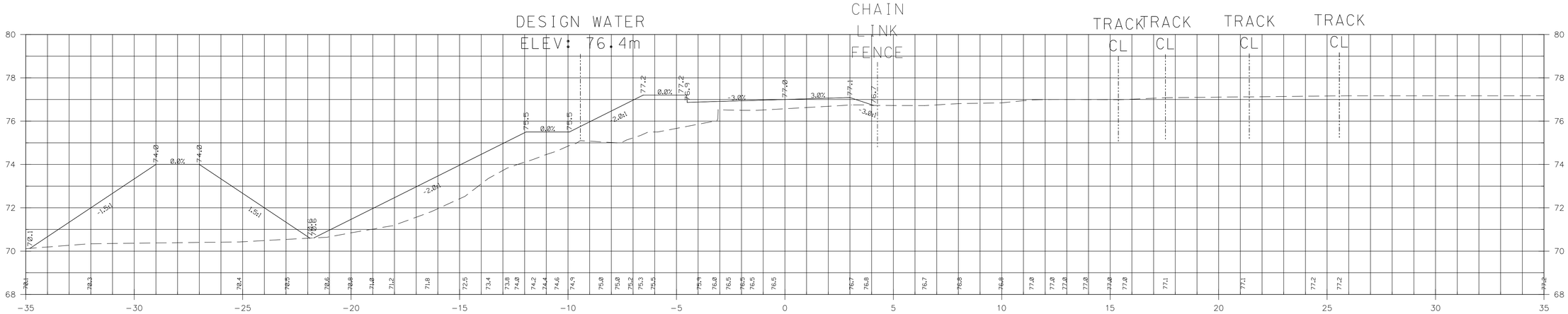


1+220.00

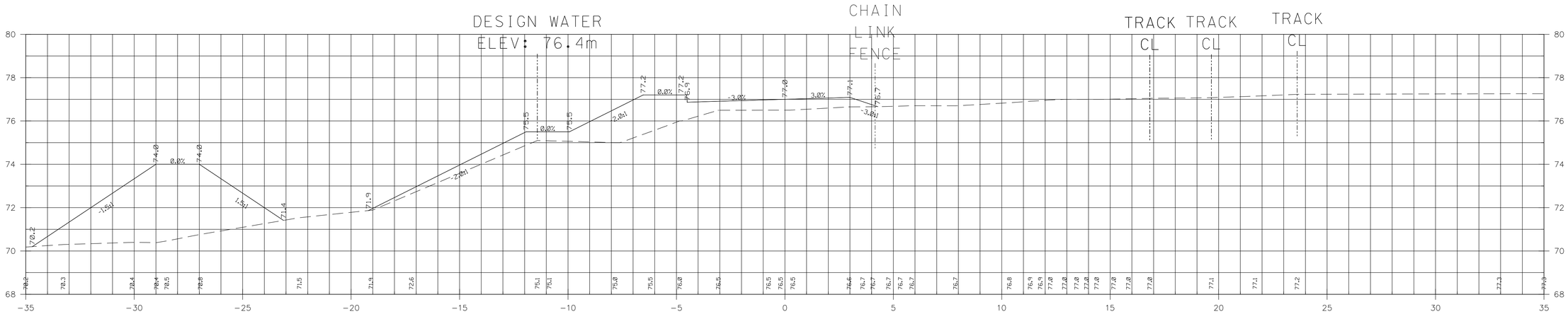
SCALE: 1:100 STA 1+280.00 TO STA 1+320.00



1+320.00

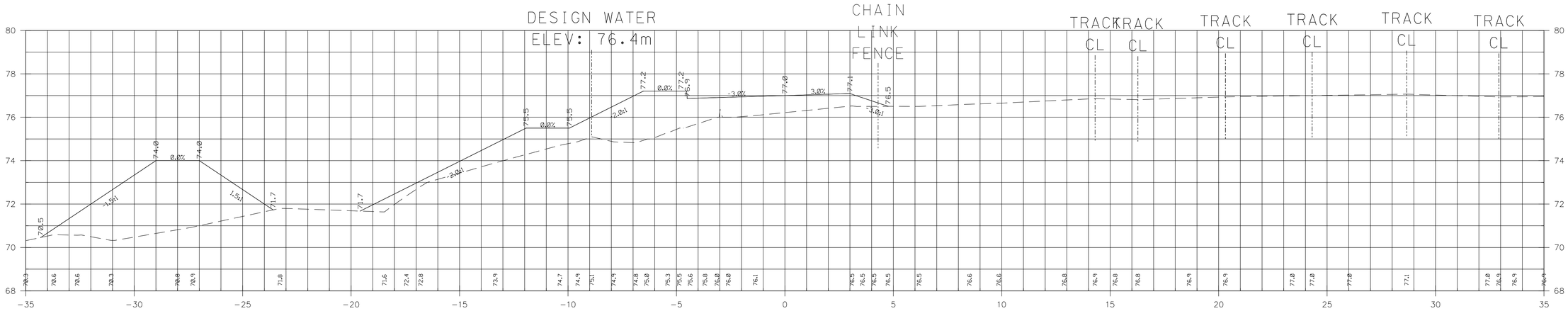


1+300.00

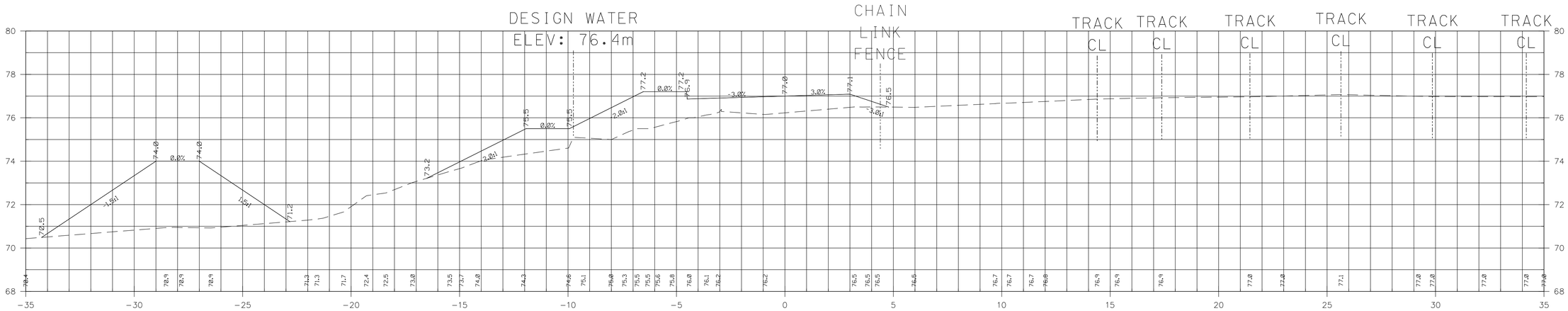


1+280.00

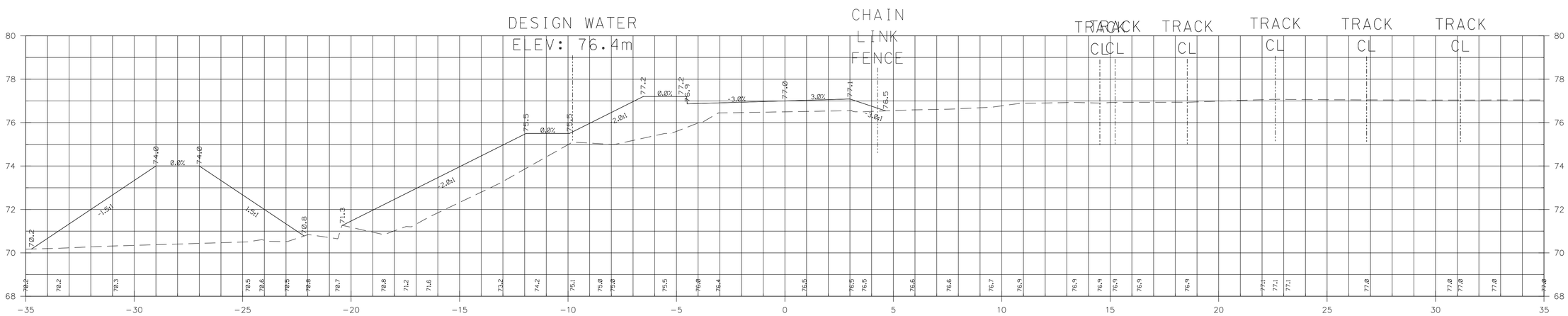
SCALE: 1:100 STA 1+340.00 TO STA 1+380.00



1+380.00

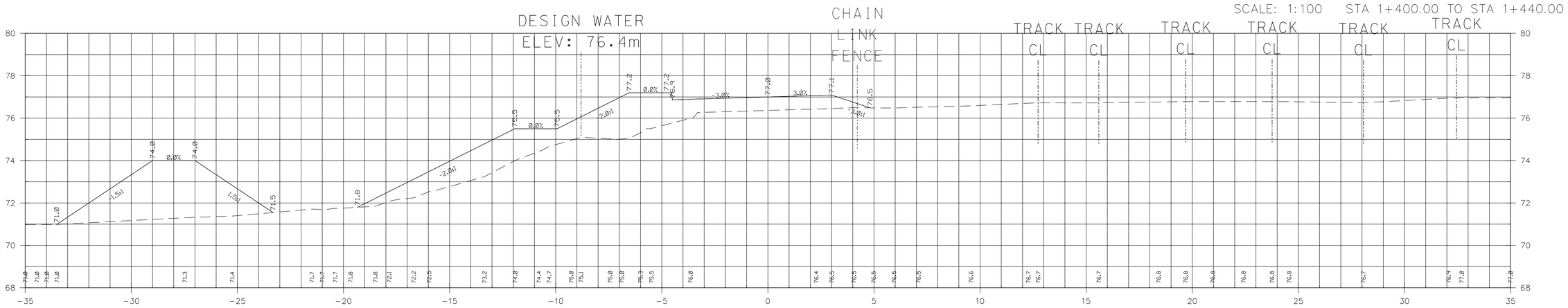


1+360.00

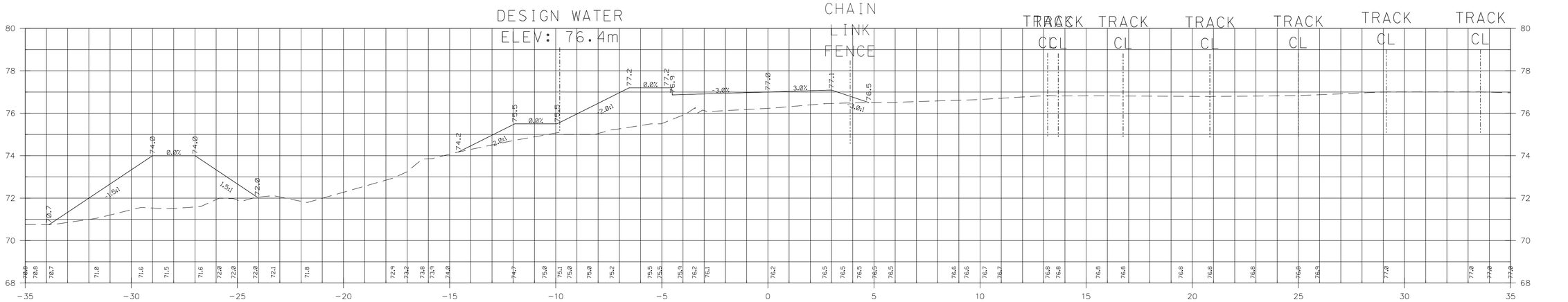


1+340.00

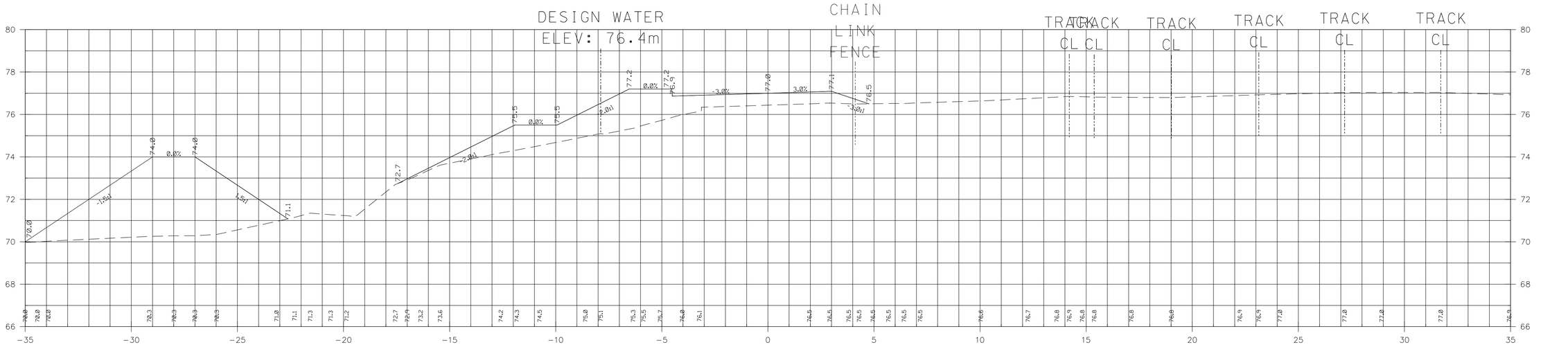
SCALE: 1:100 STA 1+400.00 TO STA 1+440.00



1+440.00

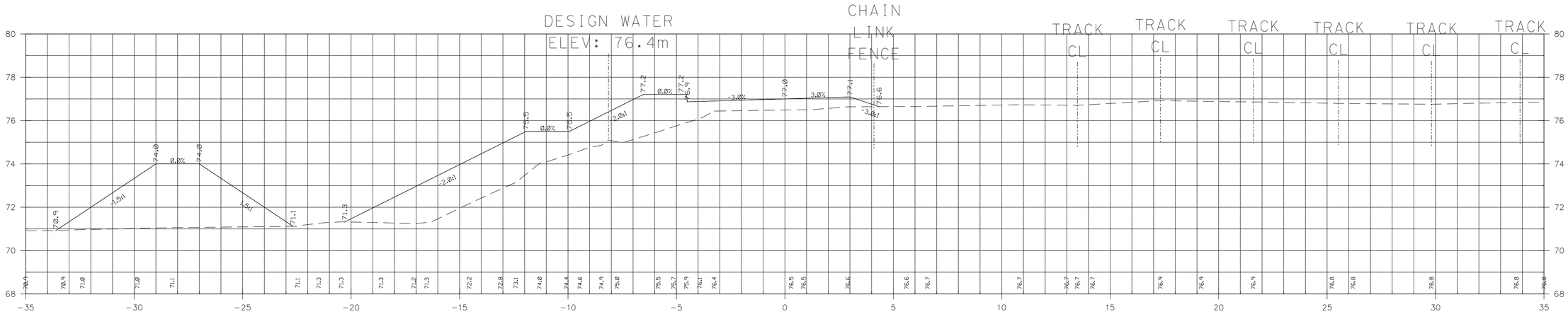


1+420.00

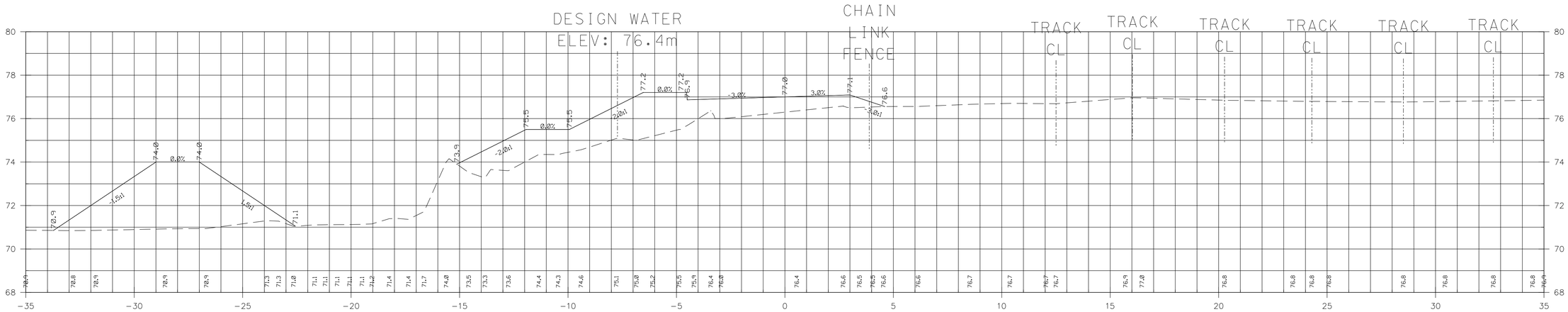


1+400.00

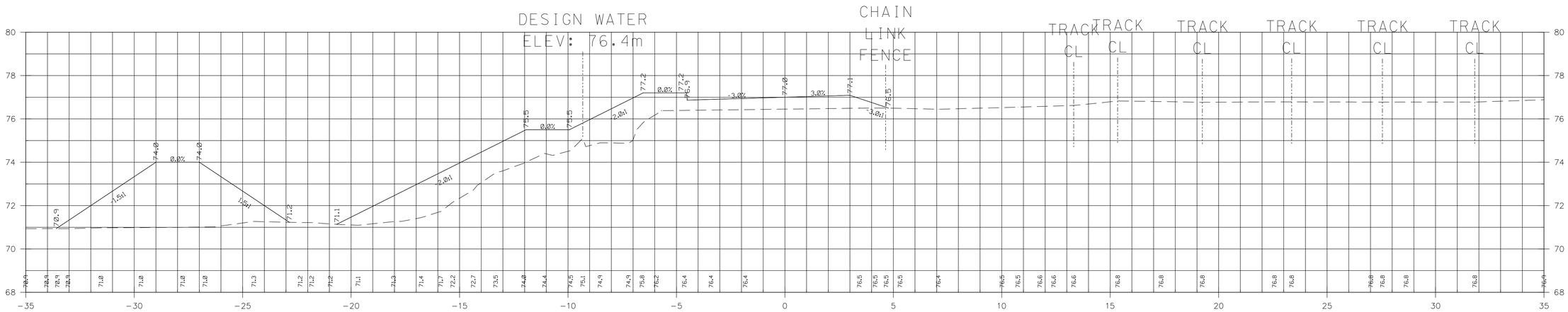
SCALE: 1:100 STA 1+460.00 TO STA 1+500.00



1+500.00

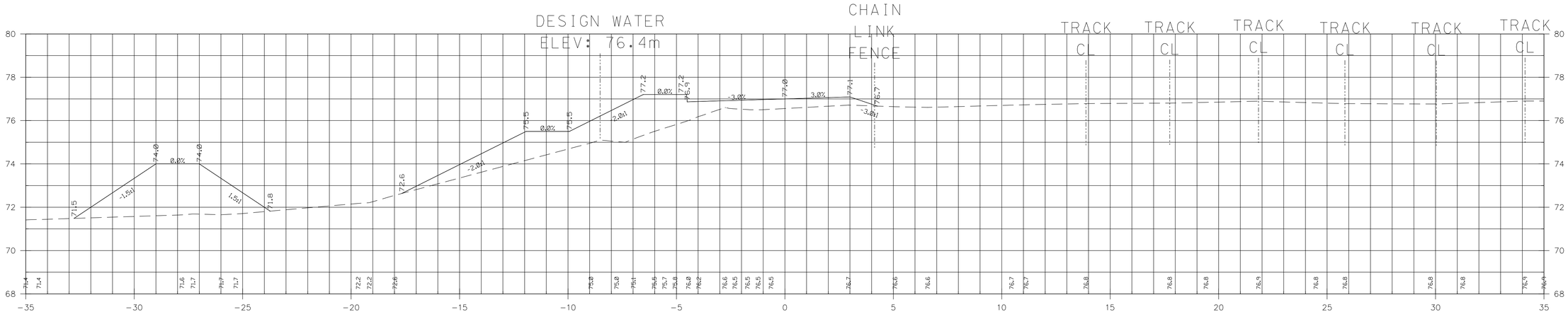


1+480.00

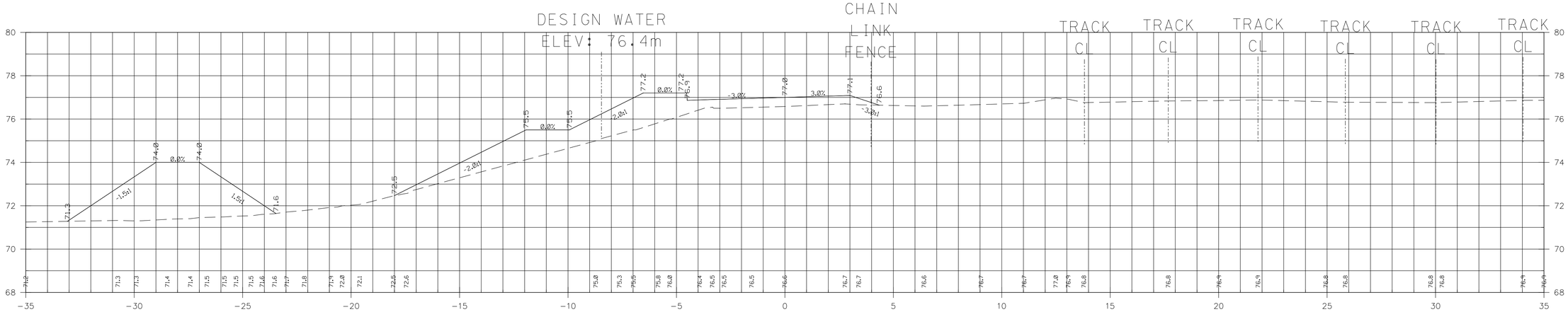


1+460.00

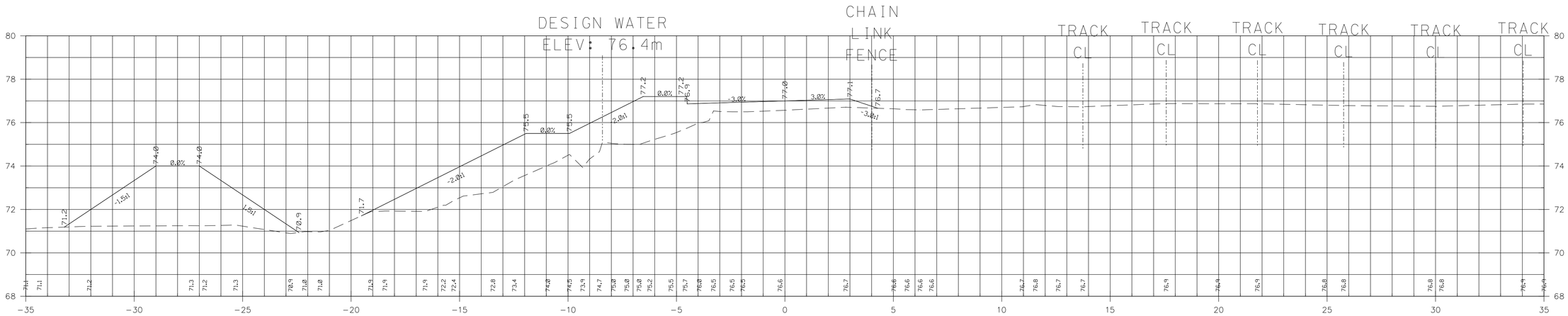
SCALE: 1:100 STA 1+520.00 TO STA 1+560.00



1+560.00

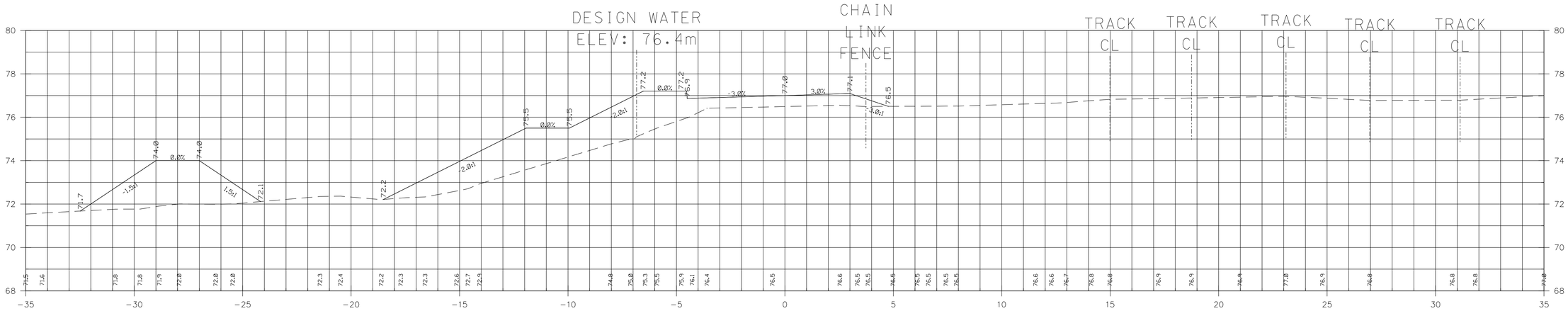


1+540.00

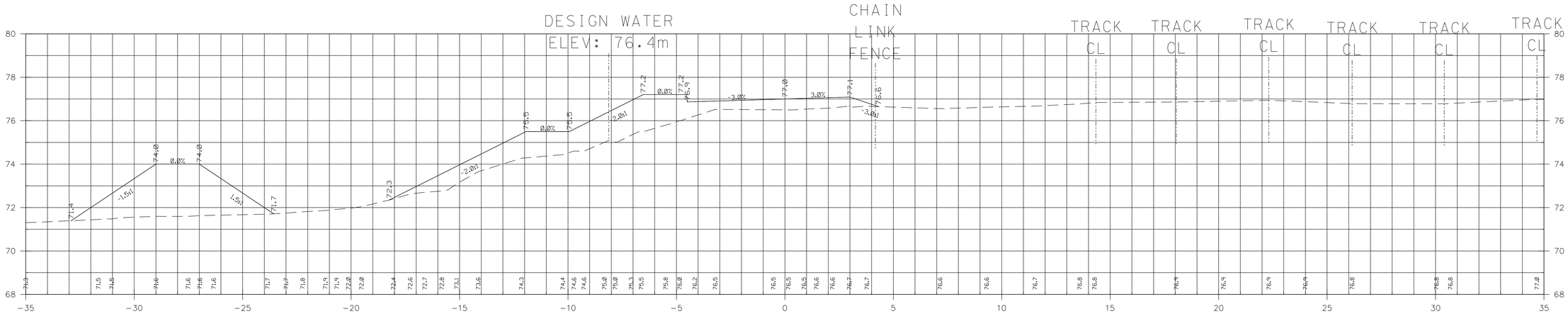


1+520.00

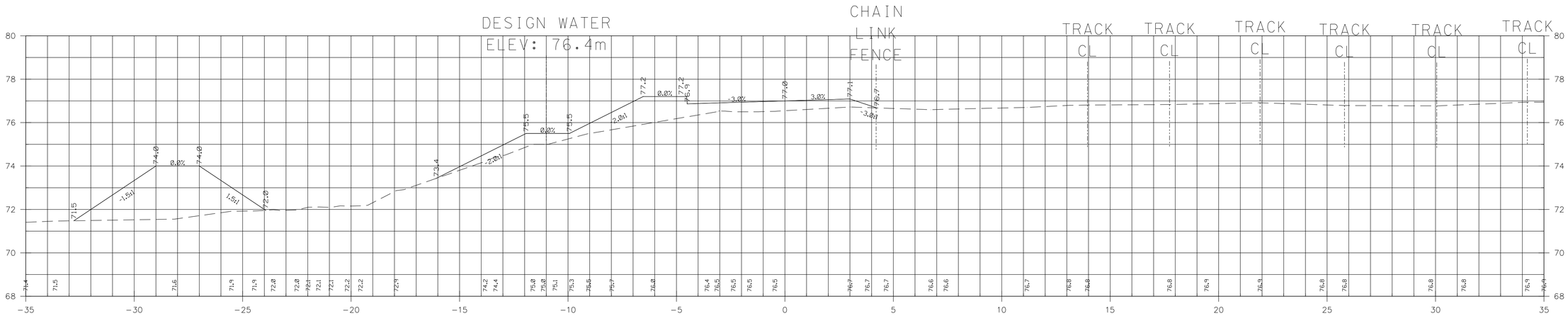
SCALE: 1:100 STA 1+580.00 TO STA 1+620.00



1+620.00

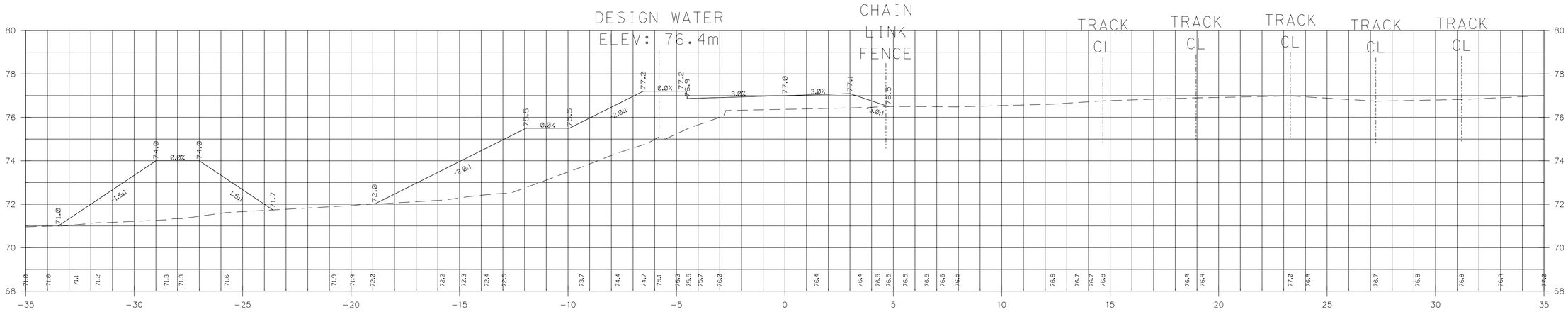


1+600.00

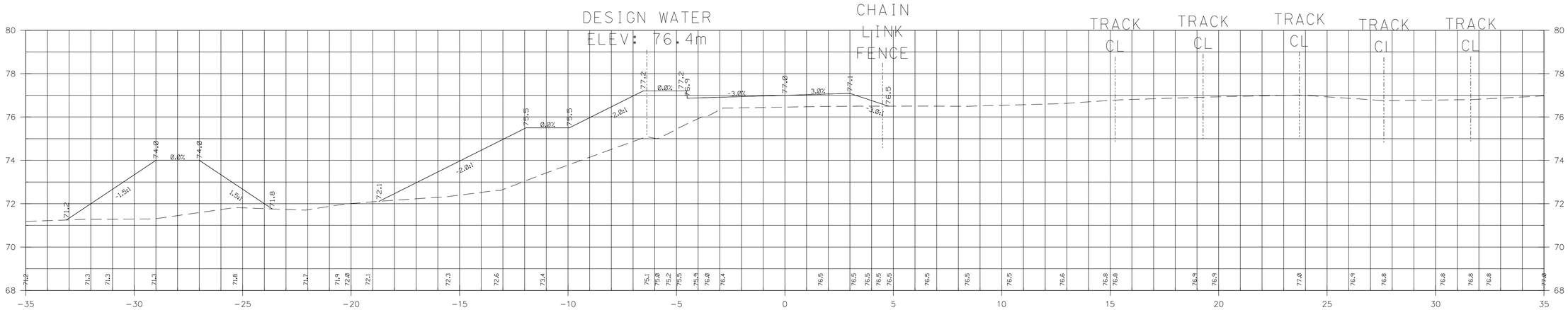


1+580.00

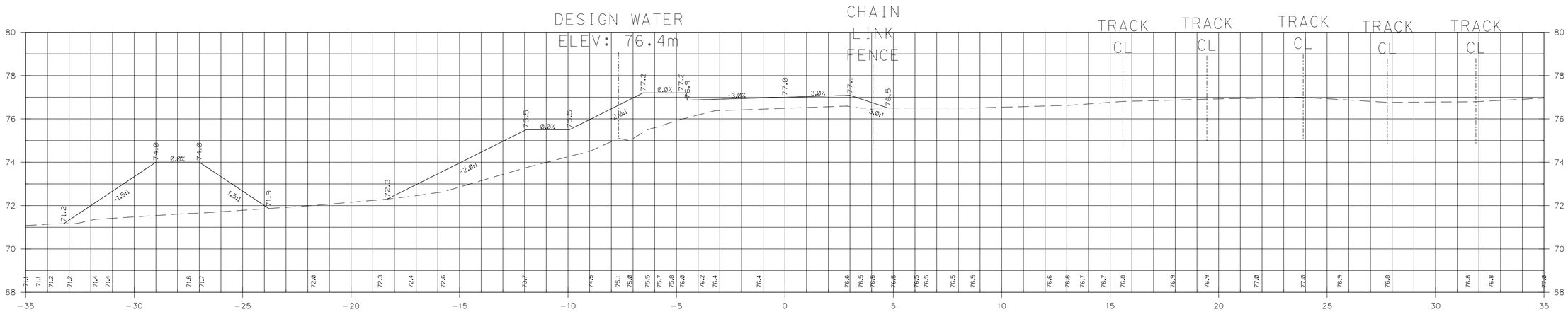
SCALE: 1:100 STA 1+640.00 TO STA 1+680.00



1+680.00

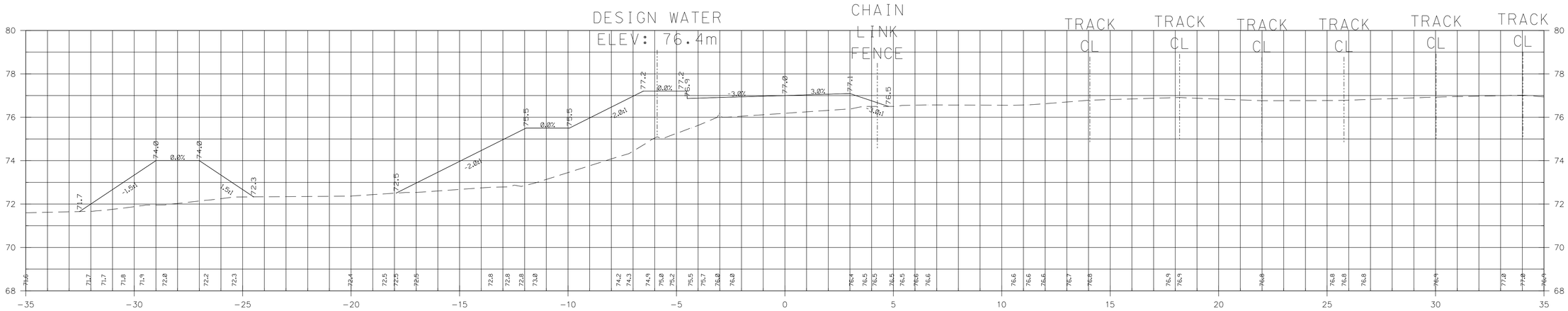


1+660.00

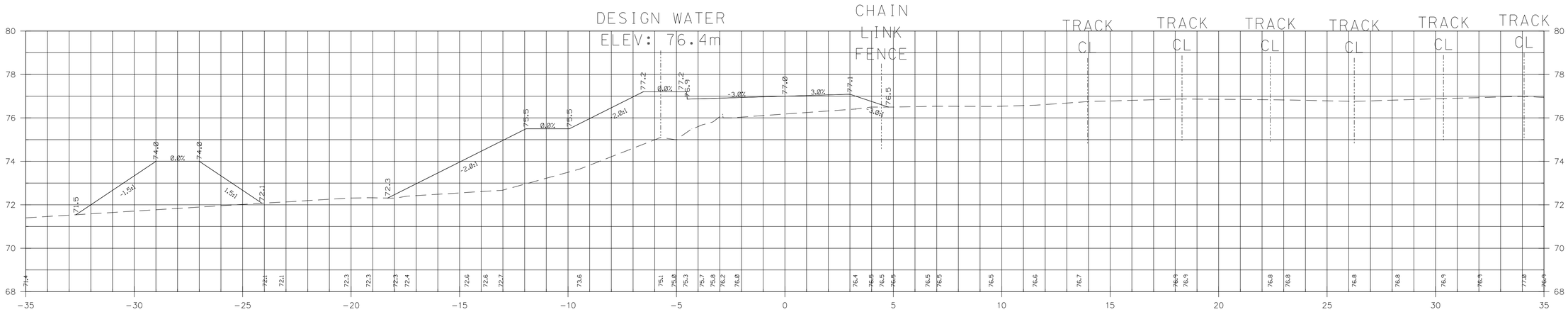


1+640.00

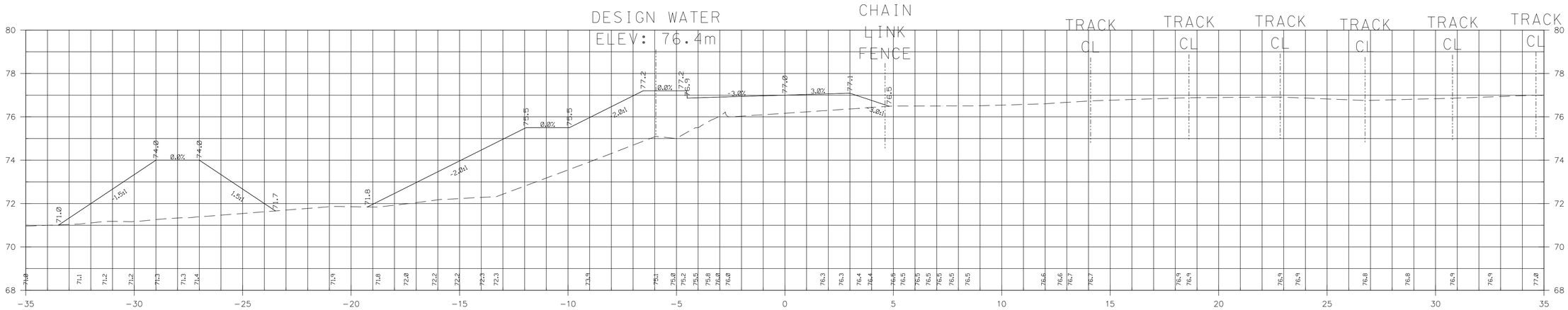
SCALE: 1:100 STA 1+700.00 TO STA 1+740.00



1+740.00

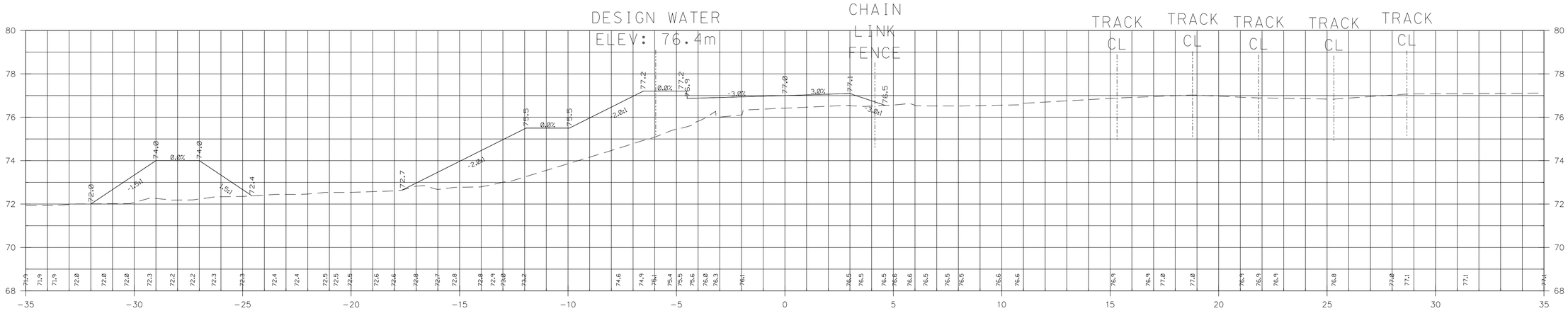


1+720.00

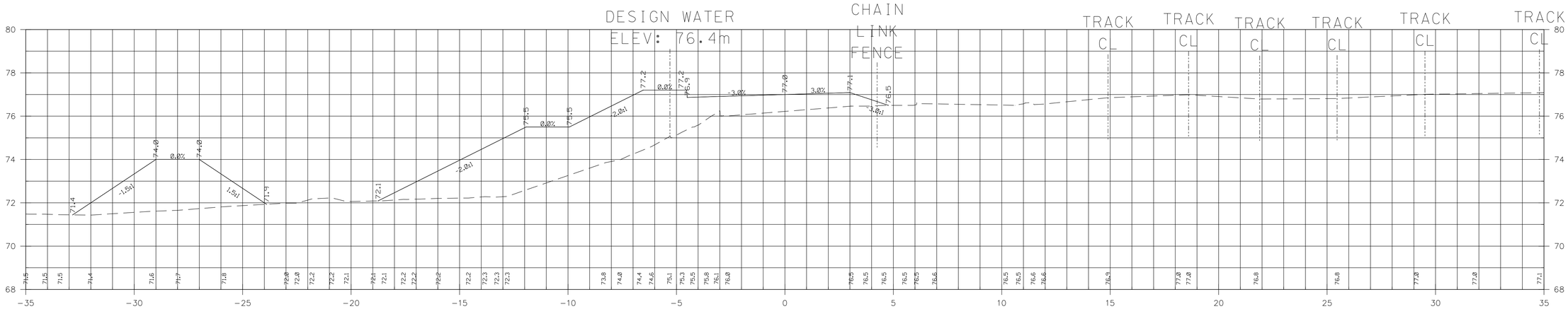


1+700.00

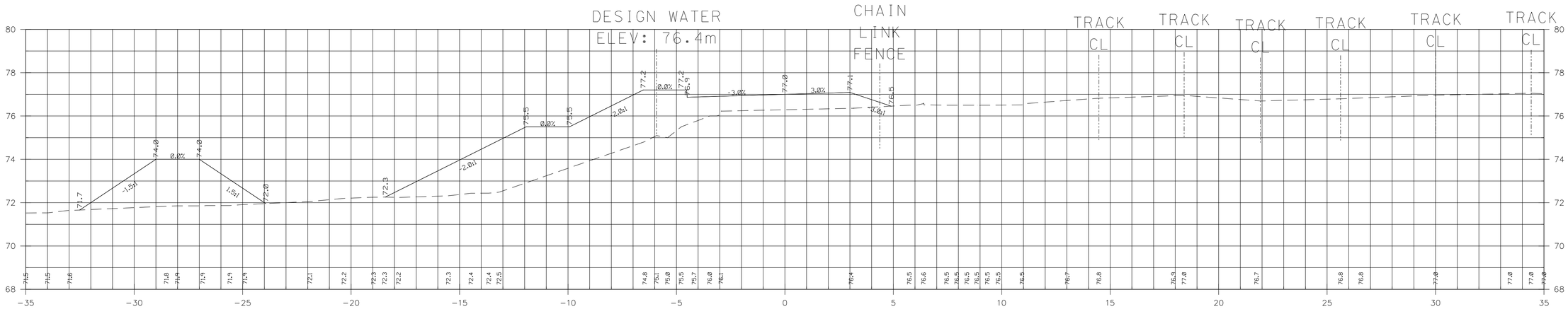
SCALE: 1:100 STA 1+760.00 TO STA 1+800.00



1+800.00

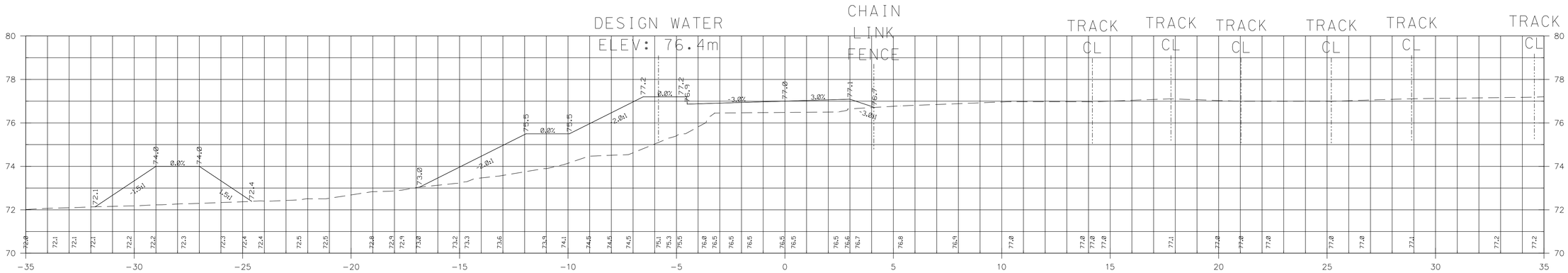


1+780.00

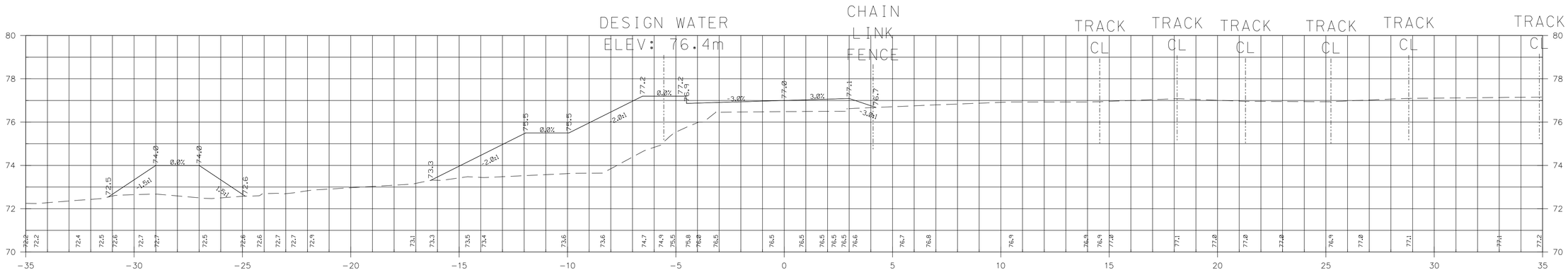


1+760.00

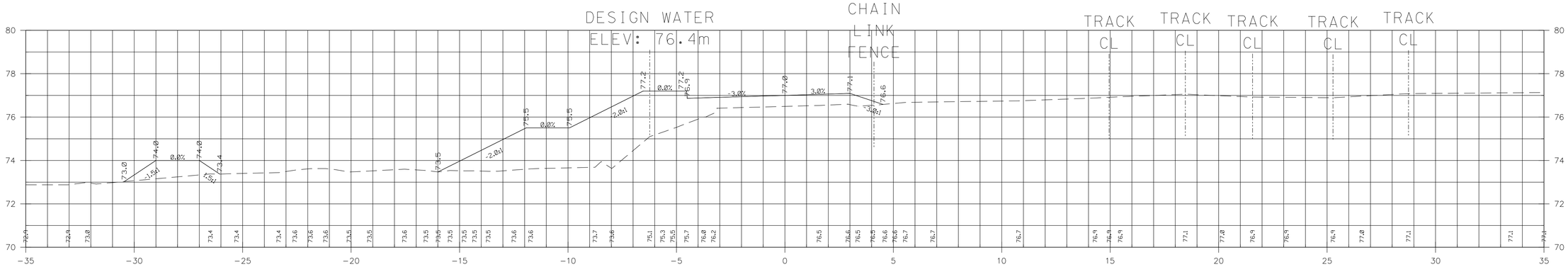
SCALE: 1:100 STA 1+820.00 TO STA 1+860.00



1+860.00

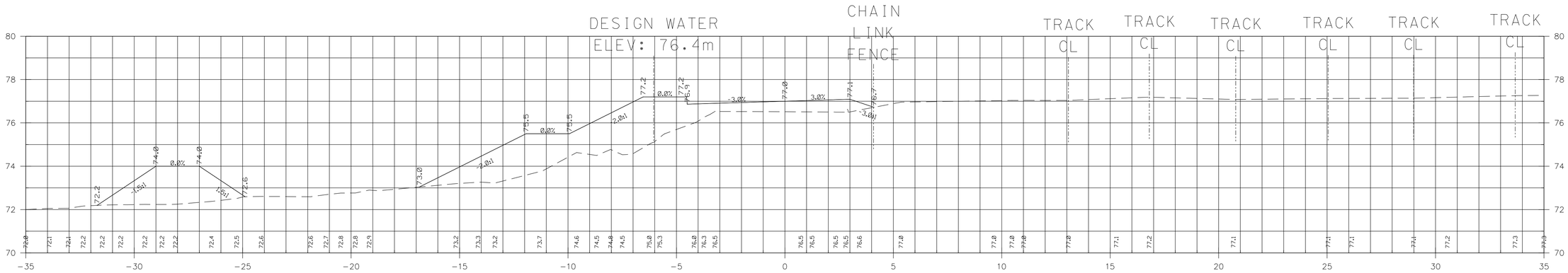


1+840.00

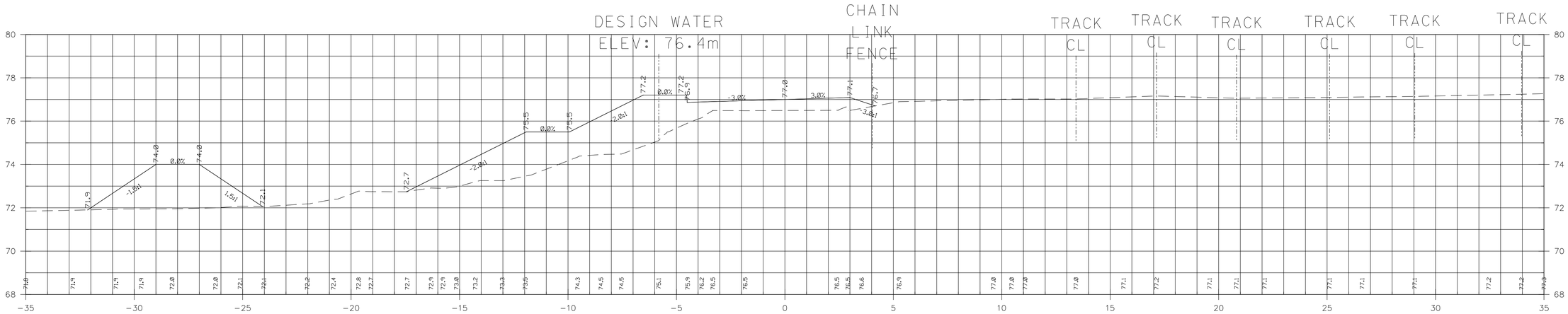


1+820.00

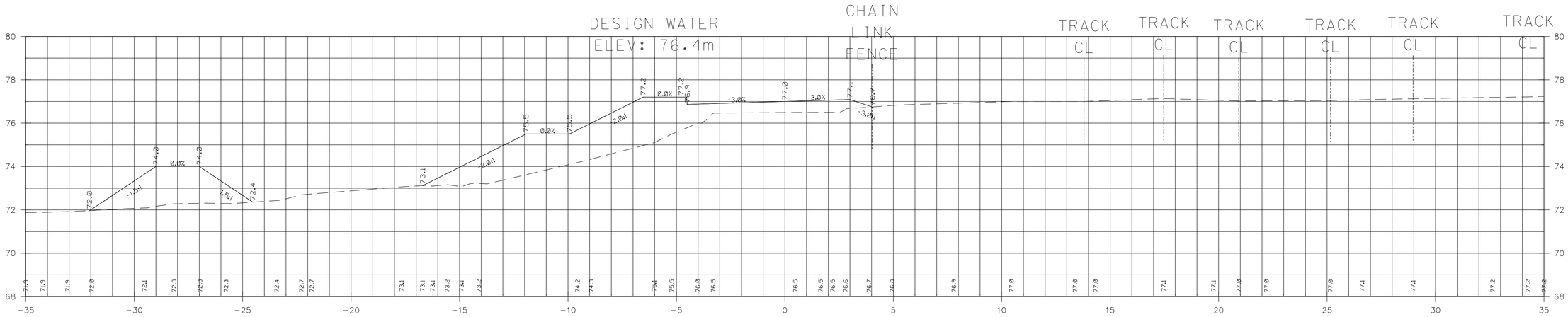
SCALE: 1:100 STA 1+880.00 TO STA 1+920.00



1+920.00

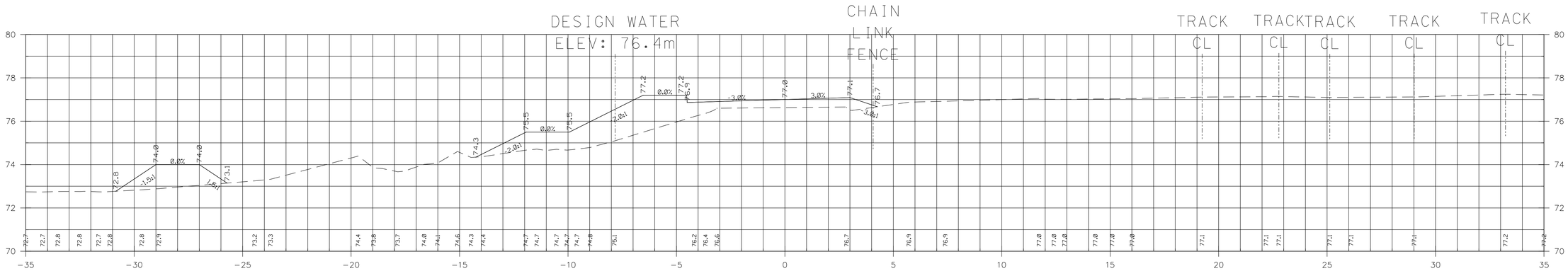


1+900.00

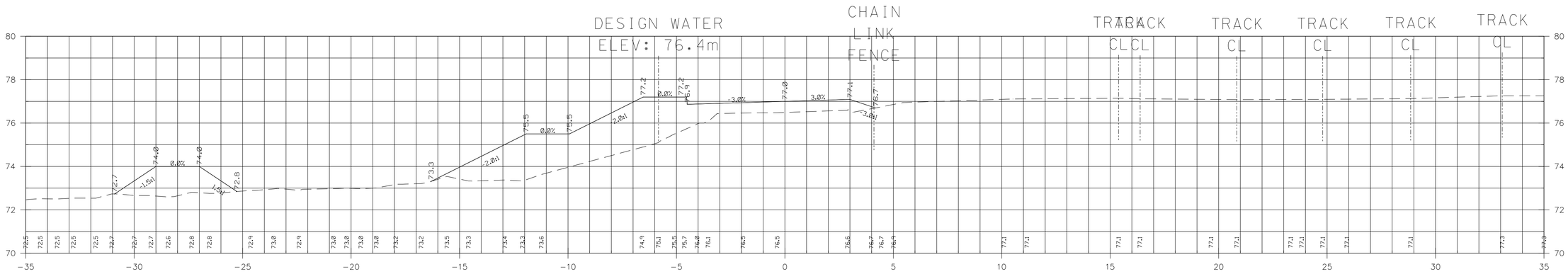


1+880.00

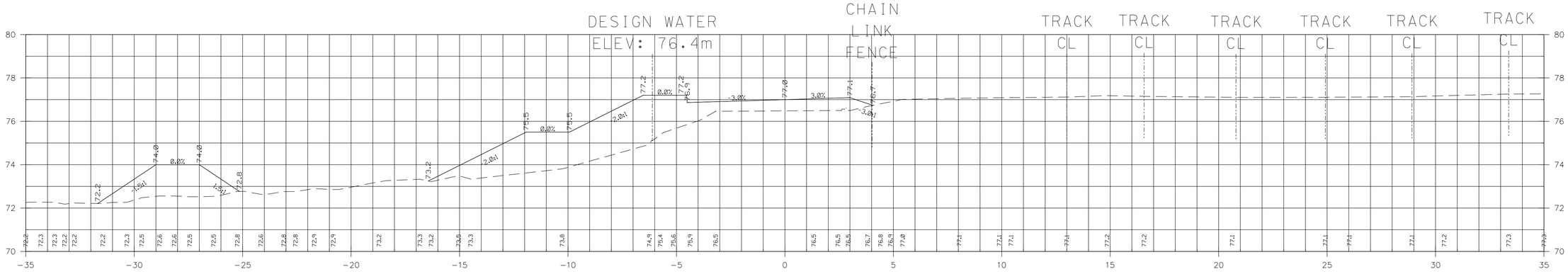
SCALE: 1:100 STA 1+940.00 TO STA 1+980.00



1+980.00

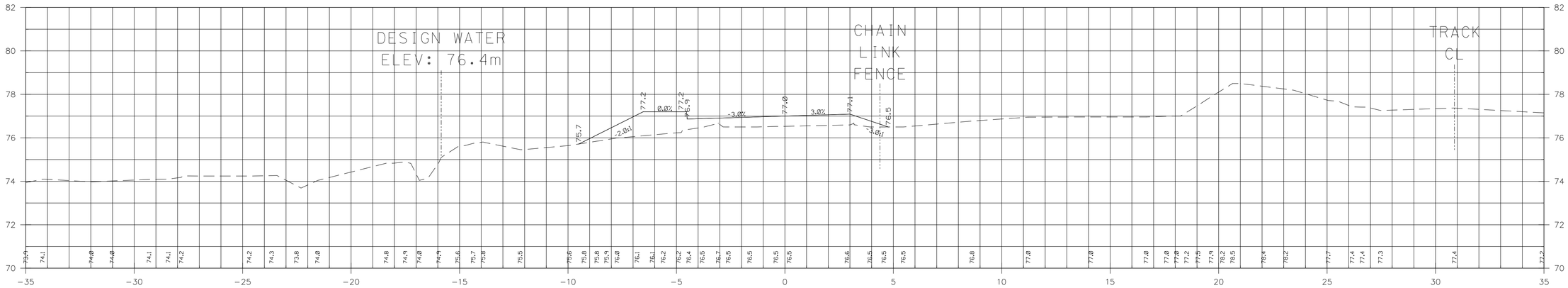


1+960.00

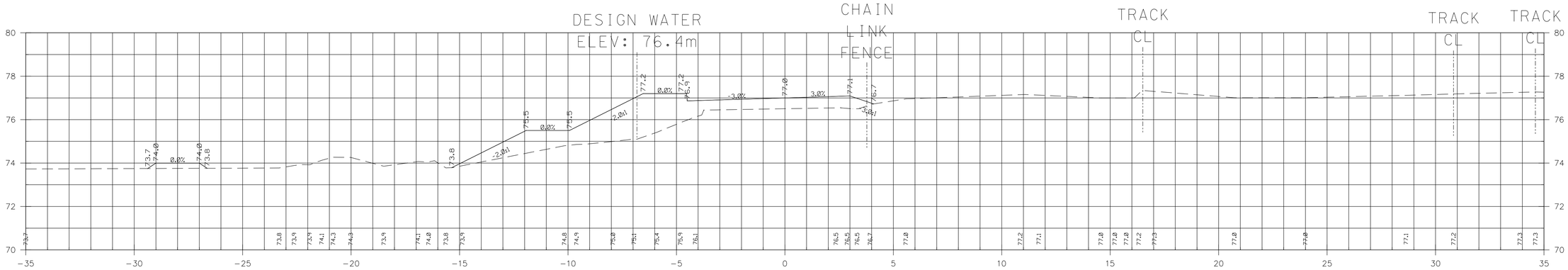


1+940.00

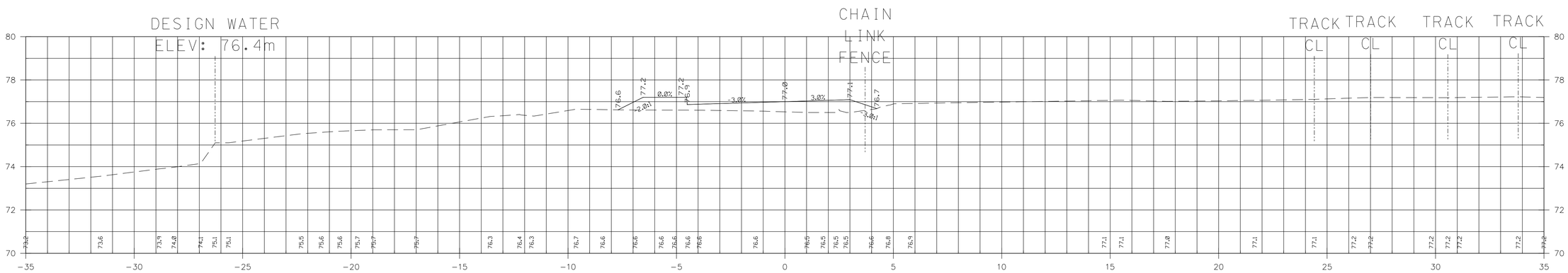
SCALE: 1:100 STA 2+000.00 TO STA 2+040.00



2+040.00



2+020.00



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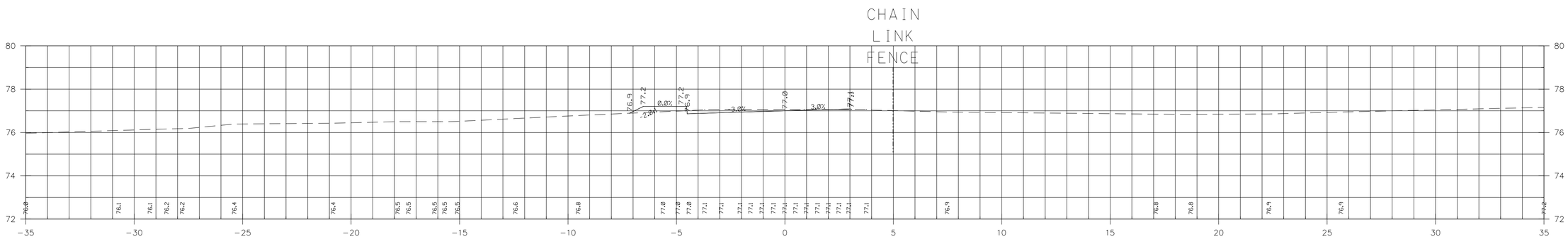
SCALE: 1:100 STA 2+060.00 TO STA 2+062.16



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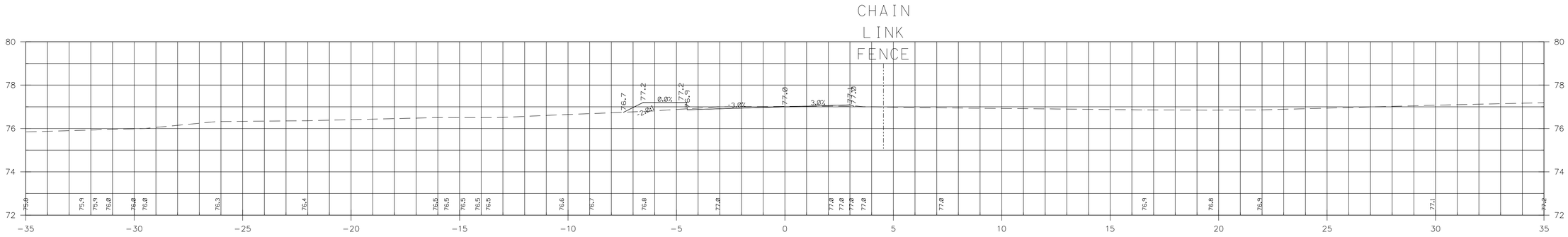

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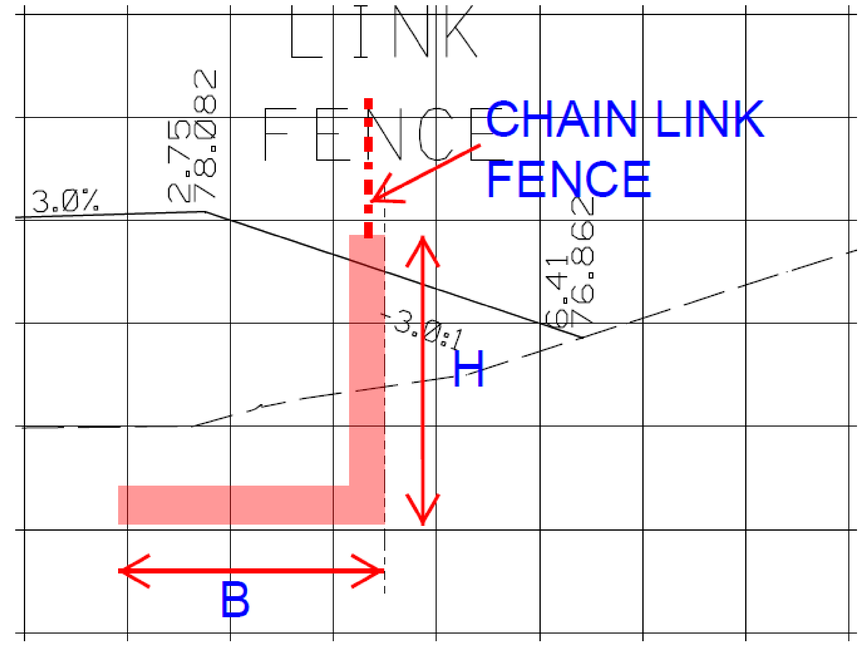
Appendix B

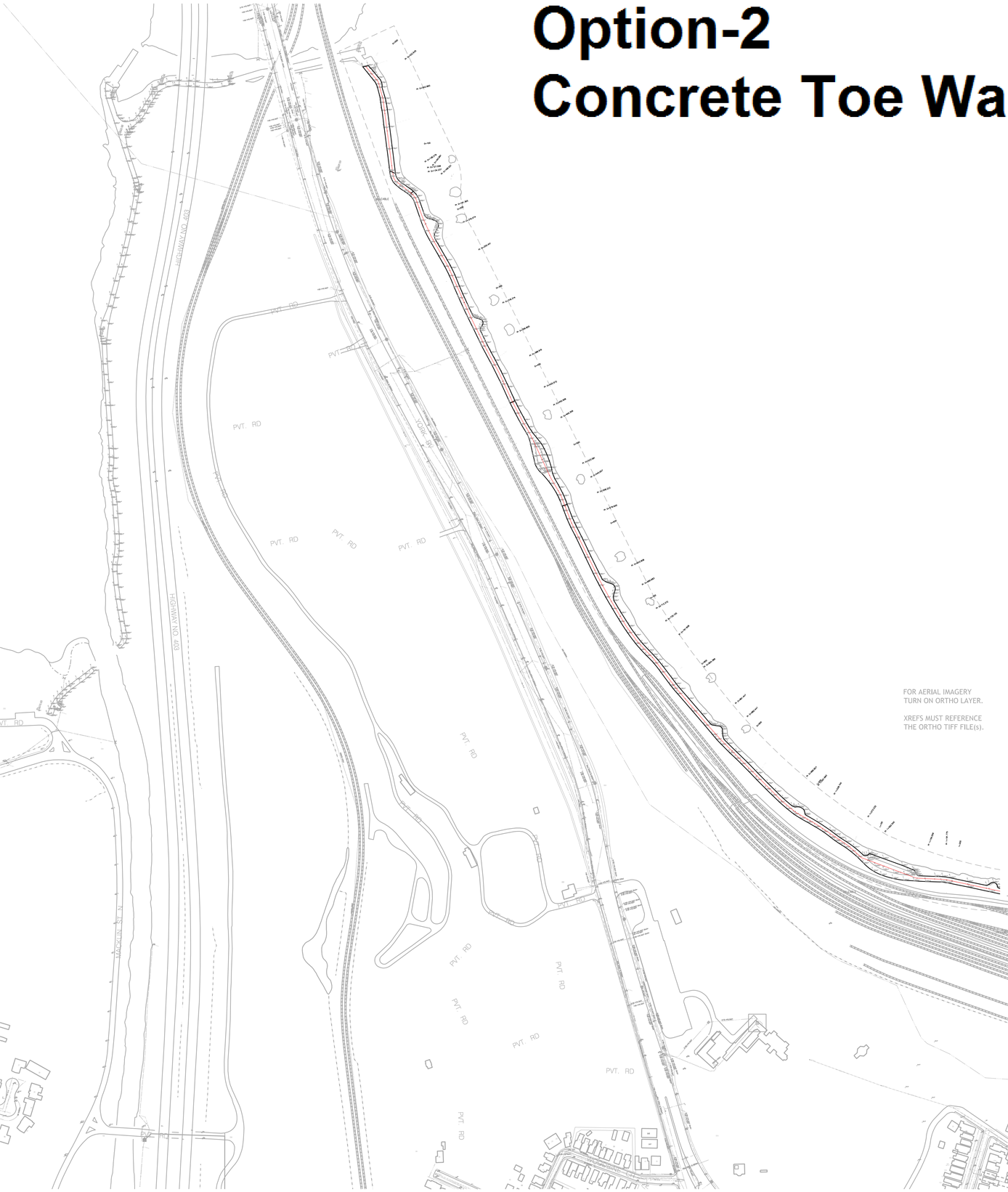
Option 1 – Concrete Retaining Wall Plan and Section
Option 2 – Concrete Toe Wall Plan and Section

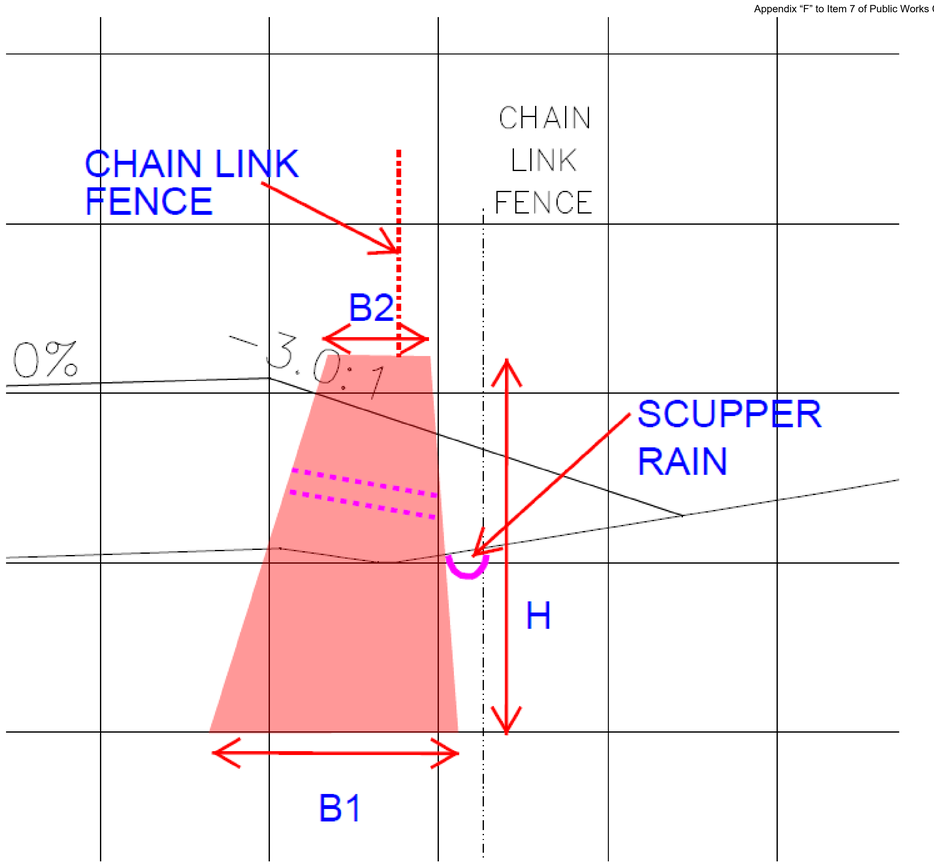
Option-1
Concrete Retaining Wall



H (m)	B (m)	Member Thickness (m)	Wall Length (m)	Concrete Volume (cu.m)
3.00	3.00	0.30	20	34
2.75	2.75	0.30	780	1217
2.50	2.50	0.30	940	1325
2.25	2.25	0.30	90	113
2.00	2.00	0.30	107	119
1.75	1.75	0.30	75	72
Wall Not Required	-	-	50	-
		Total	2062	2881

Option-2
Concrete Toe Wall





H (m)	B1 (m)	B2 (m)	Wall Length (m)	Concrete Volume (cu.m)
1.00	0.90	0.45	520	351
1.50	1.10	0.45	140	109
Wall Not Required	-	-	1402	-
		Total	2062	460

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Appendix C

Civil Cost Breakdown
Structural Cost Breakdown

Option 1

Civil Cost Estimate

Material	Quantity	Units	Unit Cost	Cost ($)
Earth Excavation (Excluding Removal of Unsuitable Materials)	0	m^3	25	0
Earth Borrow	22,000	m^3	8	176,000
HL3 Asphalt (50mm)	1,900	t	130	247,000
Granular A (150mm)	5,200	t	30	156,000
Granular B (300mm)	8,700	t	28	243,600
Removal of Unsuitable Materials	6,700	m^3	23	154,100
	SubTotal Cost			976,700
	Plus 20% Contingency			195,340
	Total Construction Cost			1,172,040
	10% Engineering Fees			117,204
	Total Cost			**1,289,244**
	Total Cost per m (2000m)			**700**

*rounded up to nearest 100

Option 2

Civil Cost Estimate

Material	Quantity	Units	Unit Cost	Cost ($)
Earth Excavation (Excluding Removal of Unsuitable Materials)	1,600	m^3	25	40,000
Earth Borrow	3,300	m^3	8	26,400
HL3 Asphalt (50mm)	1,900	t	130	247,000
Granular A (150mm)	5,200	t	30	156,000
Granular B (300mm)	8,700	t	28	243,600
Removal of Unsuitable Materials	5,900	m^3	23	135,700
	SubTotal Cost			848,700
	Plus 20% Contingency			169,740
	Total Construction Cost			1,018,440
	10% Engineering Fees			101,844
	Total Cost			**1,120,284**
	Total Cost per m (2000m)			**600**

*rounded up to nearest 100

Option-1 Concrete Retaining Wall

Item	Unit	Quantity	Unit rate	Cost
Excavation	m^3	14,000	70	980,000
300 Thk Granular	m^3	1,900	80	152,000
Rebar	Tonne	300	3,500	1,050,000
Concrete	m^3	2,900	1,350	3,915,000
Contigency			20%	1,219,400
Design Fee			10%	609,700
Total				7,926,100

Cost per m Length	7.926E6 / 2062 =	**3,844**

Option-2 Concrete Toe Wall

Item	Unit	Quantity	Unit rate	Cost
Excavation	m^3	1,420	70	99,400
300 Thk Granular	m^3	360	80	28,800
Concrete	m^3	550	1,350	742,500
Contigency			20%	174,140
Design Fee			10%	87,070
Total				**1,131,910**

Cost per m Length	1.132E6 / 2062 =	**549**

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Appendix D

Option 3 Refinement

Technical Memorandum

To:	Wes Kindree
Cc:	Michael Asante, Norton Chu
From:	Gabriela Maciel-Jobb; Nora Asadollahi
Date:	31 03 2020
Ref:	Hamilton Harbour Waterfront Trail Shoreline Protection – Preliminary Design
Subject	Preliminary Design Option 3 Stepped Revetment – Refinement

SNC-Lavalin Inc. was contracted by City of Hamilton to investigate and propose conceptual solutions for the rehabilitation of the Hamilton Harbour Waterfront Trail (HHWT) shoreline protection. The HHWT is a 3.4-kilometre-long multi-use asphalt trail that makes its way along the west shore of Hamilton Harbour from Bayfront Park through the Desjardins Canal and continues to Princess Point.

SNC-Lavalin coastal engineering team in collaboration with the civil/structural engineering team provided two budgetary design alternatives for the trail considering the adaptation to extreme events. Two additional shoreline protection alternatives were provided considering non-conventional design approaches.

The City requested SNC-Lavalin to perform a refinement for Option 3 – Stepped Revetment due to the recreational and cost benefits that the option presented when compared to the other proposed solutions.

As part of the refinement, the following tasks were conducted.

- Literature review of existing similar structures and physical model tests.
- Preliminary design calculation using formulas for similar conditions
- Conclusions and recommendations for detailed design phase.

Stepped Revetment Literature Review

Stepped revetments can reduce wave effects over the crest of a coastal protection structure by introducing slope roughness. Stepped revetments were introduced as an alternative for conventional revetments as the surface roughness reduces wave effects resulting in lower crest height. A rough surface creates higher turbulence in the flow which leads to higher energy dissipation (Ref [1],[3],[8]). Stepped revetments also provide secondary application such as tourism and recreation.

Based on available literature review, the impact of the surface roughness on the wave overtopping and run-up of stepped revetments depends on the material, type of revetment, wave height and step height. The roughness factor varies between 0.35 to 0.9 depending on the geometry and hydraulic boundary condition of the stepped revetment structure. (Ref [1], [3])

Ref. [2] analysed the wave overtopping and run-up on composite slope and concluded a reduction comparing to smooth surface revetments with a roughness factor varying between 0.65 to 0.85 for non-breaking waves and 0.35 to 0.7 for breaking waves.

Kerpen et al. (Ref [1], Ref [3]) conducted a model test to investigate the geometry related energy dissipation at stepped revetments. The authors stated that using stepped revetment can reduce the wave overtopping volume of breaking wave up to 60% comparing to smooth slope. Higher reduction was achieved for the case where the step size is smaller than the wave height.

Based on experimental study (Ref [3]), the overtopping reduction is highly dependent on step ratio (kh/Hm0) if the step height is larger than incident wave height, the overtopping would be reduced by 2-10%. The author (Ref [3]) stated that the overtopping prediction was done based on model scale on test results in hydraulic lab.

The physical model conducted by Van Steeg et al., 2018 (Ref [4]) for stepped revetment concluded that the roughness reduction coefficient depends on step heights, slope, wave height and overtopping discharge. The authors recommended a formula for roughness coefficient based on physical model results.

Gallach-Sánchez, 2018 (Ref [9]) investigated the effect on the overtopping of roughness on the slope considering two types of roughness elements are selected to be tested: blocks and ribs (due to a lack of reduction of the overtopping rates the blocks were later transformed into ribs) and stepped revetments (with different step heights). The results showed higher overtopping reduction for milder slope as well as smaller overtopping reduction as the breaker parameter increases.

Schoonees et al., 2018 (Ref [10]) concluded that roughness factor is highly dependent on the slope. Based on their results, milder sloped stepped revetment leads to less reductive effect of the steps (higher roughness) on wave overtopping for breaking waves. The authors explained the higher roughness with longer run-down time of waves due to milder slope which result in a residual layer of water on the revetment for the next approaching wave and subsequent less roughness.

Preliminary Design

Due to the lower trail elevation, recent high water levels and wind-wave exposure, the preliminary design of a shoreline protection for the HHWT had to consider unique solutions to increase the trail protection and reduce overtopping. The following features were included in the design to mitigate the wave effects.

- Berm
- Partially stepped upper slope
- Milder lower slope
- Increased crest width

The design is a hybrid structure (combination of conventional and stepped revetment), including a berm to dissipate the design breaking wave energy and wider crest to reduce wave effects.

Since there are limited resources available in the literature for stepped revetments with more complex geometry and the available experimental studies were conducted specifically for impermeable fully stepped revetments two different design approaches are used to estimate wave effects and define preliminary dimensions. These approaches are stepped revetment and conventional rock revetment with berm and increased crest width.

Stepped Revetment: For this design approach the revetment is assumed to be composed fully by concrete steps. However, in the current proposed design the revetment is a hybrid structure (the upper slope are composed of stepped armour rock revetment and the lowers slope, armour rock.

The effect of berm, crest width and permeability are not incorporated as the interaction is unknown for the proposed approach. It is expected that the inclusion of berm, crest and permeable structure reduce wave effects. However, physical model tests are required to evaluate the influence. The overtopping rates was estimated using EurOtop 2018 (Ref [5]) considering roughness reduction factors from Ref [1] and Ref [2].

Larger step heights (hstair) will lead to more optimal roughness reduction. Considering that public access is a requirement, the stair height was limited to 0.5 m.

Figure 1 and Figure 2 show the model tests conducted from Ref.[4] and Ref.[1].

Figure 1 Model test (scale 1:10) of stepped revetment for 1V:3H slope - Ref. [4]

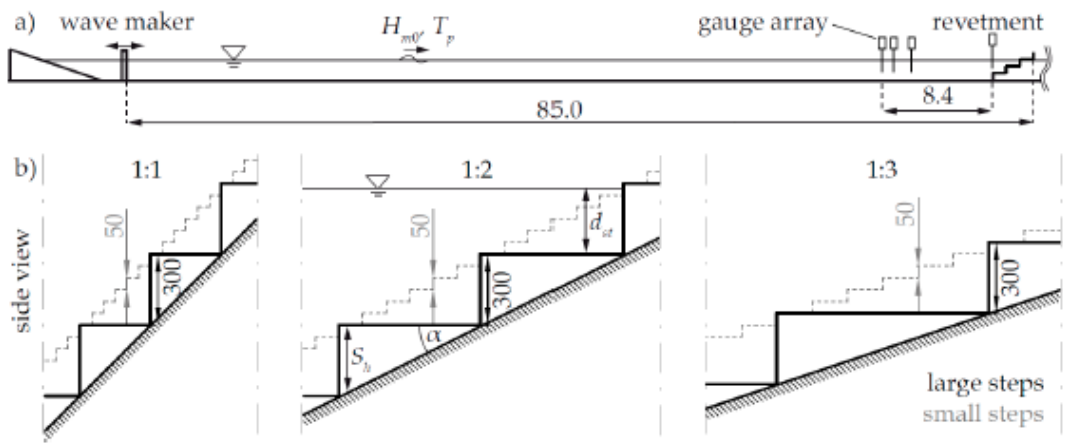

Figure 2 Model tests from Ref. []. a) Side view of model set up with gauge positions (units in meter). b) Side view of the tested step geometries (units in mm)

Conventional Revetment: In this design approach the influence of berm, crest, and permeability is considered using conventional revetment design. The upper slope was considered on average 1V:2H and the lower slope 1V:3H. The associated wave effects were estimated according Ref [5].

Figure 3 shows the dimensions of the revetment cross section used to calculate wave effects, adapted from Ref. [5].

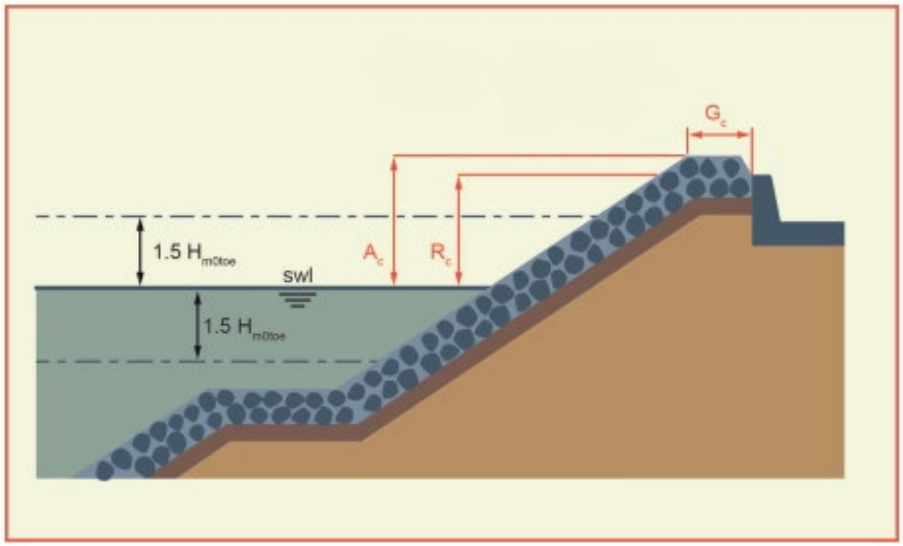

Figure 3 Schematization of revetment cross section for run up and overtopping calculation considering berm and crest width (adapted from Ref. [5]).

The proposed design is composed of geometries from these two approaches, but the use of concurrent reduction factors were not tested. Physical model tests should be carried out to evaluate the design and provide with certainty the reduction of wave effects.

Changes on the geometries proposed in the available references were made to adapt the protection to the site conditions and limitations. The proposed structure considered the following assumptions, to be confirmed in physical model.

- All references used for this preliminary design considered impermeable revetment. The proposed preliminary cross section considers boulder steps to provide permeability to the structure and drainage of potential overtopping volume during storm events. Physical model is required to assess the improvement in terms of wave effects reduction using permeable stepped revetment.

- For this preliminary design the EurOtop 2018 (Ref [5]) were used as the general equations for relative overtopping discharge under breaking and non-breaking waves.

- The effect of armour crest is not considered in the concept design of stepped revetment. Generally, the wider the crest, more energy can be dissipated, and the overtopping will be reduced (Ref [5]). Physical model is required to confirm the suggested value for crest width as well as interaction of the reduction factor with the other parameters (i.e. roughness reduction factor in stepped revetments.)

- Toe stability design was considered to avoid undermining of steps and berm. Since the flow at the toe is shallow water condition, the same size of slope armour rock is considered. The rock size to be used in the structure toe can be confirmed during the physical model tests.

The proposed preliminary design shown in Figure 4 is a combination of the conventional revetment with berm and wider crest and the stepped revetment for the upper slope. The step height (hstair) and width are 0.5 and 1 m, respectively in a 1V:2H slope. The final dimensions must be confirmed by physical model tests.

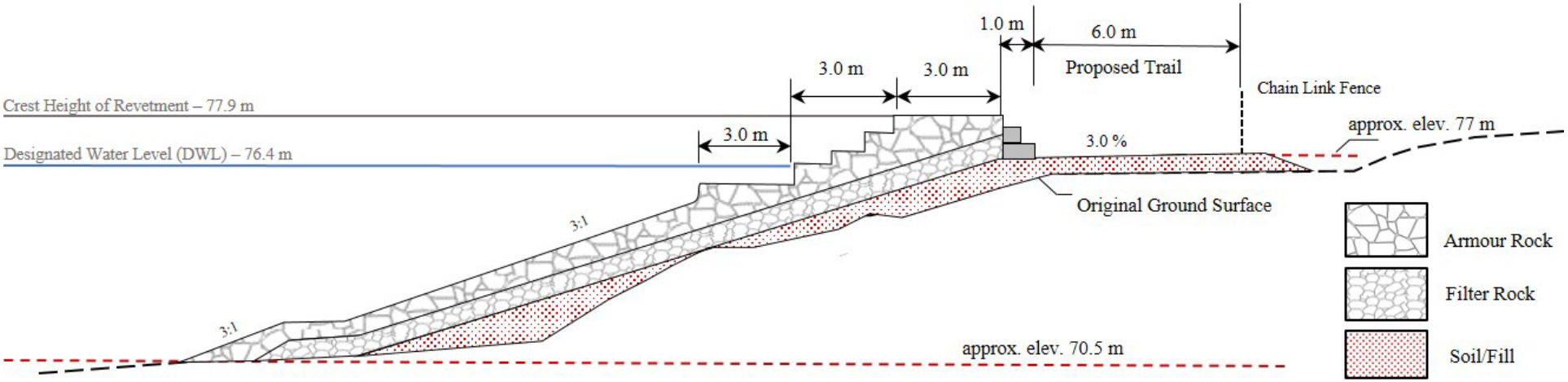

Figure 4: Typical Cross -Section of Stepped Revetment

Cost Estimate

The armour rock size for this proposed revetment is smaller than the previous options, since the lower slope was reduced to 1V:3H. The cost of the rock was also reduced approximately 25% when compared to Option 1 and previous Option 3. The volume for this proposed revetment is larger than the previous solution, also because of the change in the lower slope. A preliminary design of a toe protection was included in this refinement, also contribution to the volume increase.

A summary of the linear cost is shown in Table 1. The overall linear cost is slightly different than the previous considering the change in the lower slope and toe protection increasing the armour volume, and the reduction of armour rock size.

Table 1 Refined Option 3 Cost Estimate

Option	Shoreline Protection	Trail (Civil)	Retaining/Toe Wall (Structural)	Total
3*	$7,350 / m	$600 / m	$550 / m	$8,500 / m

* Refined Option 3

Conclusions and Recommendations

The stepped revetment refinement focused in identifying examples of studies and design to adapt the cross section geometry to a more representative preliminary design.

The characteristics of the existing experiments and design of stepped revetments differ from the proposed HHWT preliminary design. However, elements of these experiments were used to analyse and propose preliminary dimensions and features adapting to the Hamilton Harbour conditions and limitations.

The definition of the steps height and width are preliminary and must be defined in collaboration with landscape architect before being tested. Access to the revetment was preliminary assumed to be steps, it also needs to be confirmed with landscape architect.

Limited information regarding the relative position of Designated Water Level (DWL) relative to the step position is available. Gallach-Sánchez 2018 (Ref [9]) stated that impulsive conditions take place if DWL is on the step closest to the revetment crest which can lead to higher overtopping rate. Based on this experiment, this impulsive condition occurred for relatively smaller wave height compared to the step ratio. The influence of the position of DWL needs to be further investigated.

The proposed solution reduces the wave effects and improve the area for recreation purposes. To achieve these objectives, a berm, wide crest, and stepped upper slope were considered. There is no study indicating the influence of these features used concurrently in a design or model. Tests in a physical model are required to investigate the interaction of these roughness coefficients in the reduction of wave effects.

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