Appendix 9.2 Drainage Design Calculations

1. Introduction

CDM Smith Ireland Ltd (CDM Smith) was engaged by MKO, on behalf of Glenora Wind Farm DAC, to calculate greenfield drainage rates and volumes for the planning application for the Glenora wind farm development (the 'Proposed Development') at Glenora, Co. Mayo.

The Proposed Development comprises 22 no. turbines and grid connection as set out in Chapter 4 (Project Description) of the Environmental Impact Assessment Report (EIAR).

1.1 Purpose

The calculations serve to determine and communicate the expected runoff rates and drainage volumes from greenfield areas and infrastructure locations within the Proposed Development site in Glenora Forest. The calculations have been prepared in conjunction with the proposed drainage layout which is presented in **Appendix 4-4** of the EIAR. The subcatchments of infrastructure components, including access roads, which form the basis for the calculations are shown in **Figure 1**.

1.2 Statement of Authority

The calculations presented herein were prepared by Henning Moe (registered P. Geo.), a hydrogeologist with over 30 years of practical experience working with CDM Smith. Established in Ireland since 2001, CDM Smith's ISO 9001, ISO 14001 and OHSAS 18001-accredited Dublin office works on a diverse range of water and environmental projects for public and private sector clients, including the preparation of preliminary drainage designs, flood risk assessments and EIARs.

Henning Moe was supported by Jon Hunt (registered P. Geo.), a geologist with over 20 years of practical experience, who conducted site walkover surveys, and by Rajiv Pawar, a civil engineer and CAD/Civil 3D specialist with 14 years of practical experience, who assisted in preparing the drainage layout drawings in Appendix 4-4. Ruairi O'Carroll (CEng MIEI), a chartered engineer with over 20 years of practical experience, provided technical review.

2. Basis of Calculations

2.1 Greenfield Runoff

Proposed interceptor drains will capture and lead greenfield runoff to nearby water courses, as presented in **Appendix 4-4** of the EIAR. The interceptor drains will capture runoff immediately upslope from infrastructure components, including roads, and are integrated with the existing drains that are part of Coillte's ongoing forestry operations.

Calculations of greenfield runoff were performed using the IH-124 method for small catchments, <25 km^2 (Marshall and Bayliss, 1994). The IH-124 method, which is a commonly applied method for this type of assessment, calculates values of 'Q_{bar}' for each of the subcatchments in **Figure 1**[1], wherein Q_{bar} is an annual average maximum flood defined as the "*peak rate of flow from a subcatchment for the mean annual flood with a return period of approximately 2 years*".

[1] The subcatchments were delineated from detailed Lidar surveys (see Chapter 9 of the EIAR).

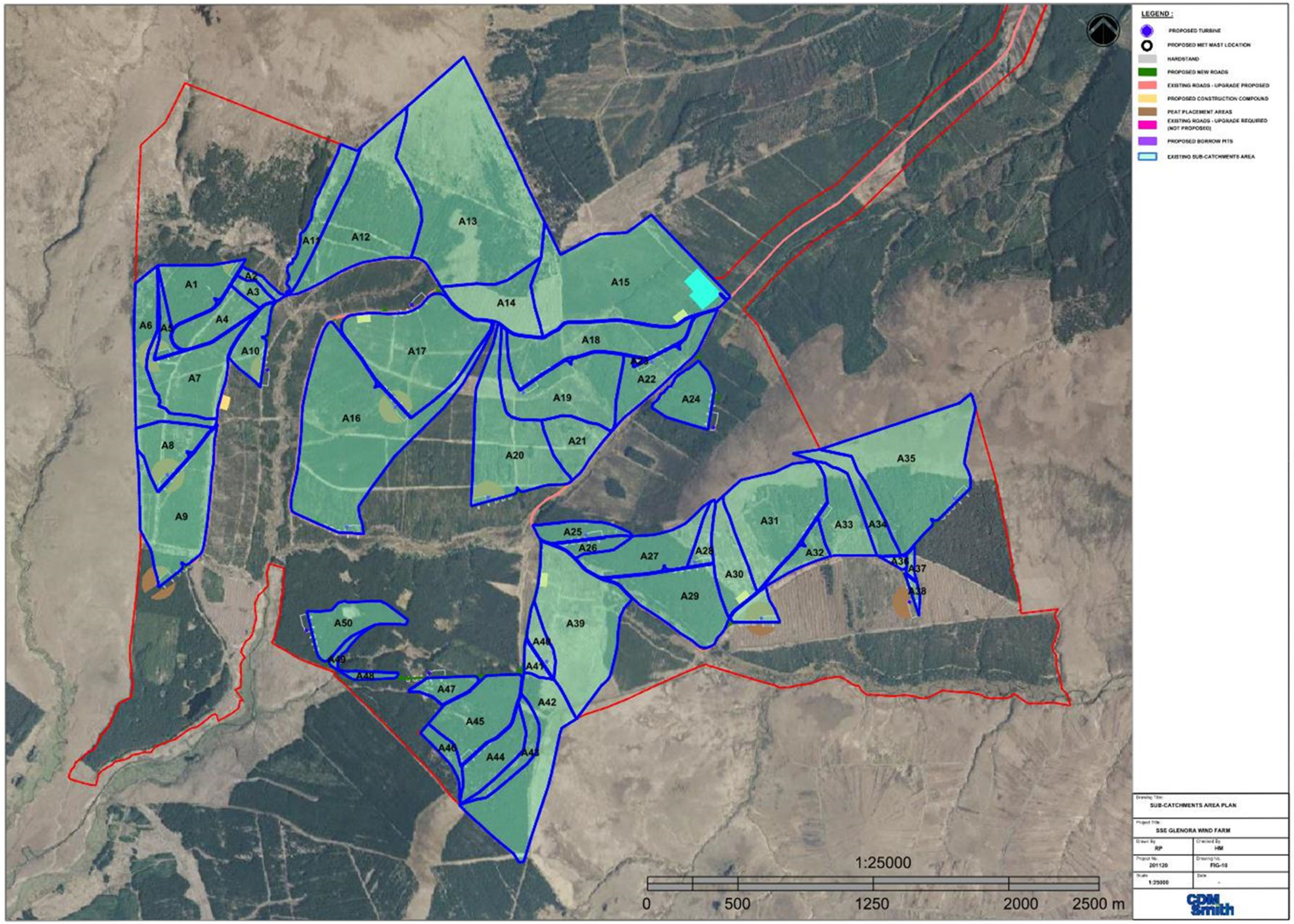

Figure 1: Subcatchments of Proposed Infrastructure Components in Glenora Forest

Q_{bar} is calculated from the following equation:

$$Q_{bar}\ (m^3/s) = 0.00108 \times (0.01\times AREA)^{0.89} \times SAAR^{1.17} \times SPR^{2.17}$$

where,

- AREA = subcatchment area (m^2).
- SAAR = standard annual average rainfall (mm/yr), ca. 1,850 mm/yr for Glenora Forest based on Met Éireann long-term average annual rainfall grid for the 30-year period 1981-2010.
- SPR = standard percentage runoff coefficient for the applicable SOIL category in the subcatchment area. The SOIL category is measure of winter rainfall acceptance potential, as a percent of rainfall. Soils are classified from S1 to S5 based on runoff potential, and related input values range from 0.1 to 0.5. For the Proposed Development site, a high runoff potential value of 0.40 was selected owing to the underlying till and relatively high slopes (see Chapter 9 of the EIAR).

As an 'index flood' (an average annual peak flood), Q_{bar} was subsequently adjusted to a 'design flood' by:

- Multiplying Qbar by a national flood frequency growth factor of 1.35 for a 1 in 10 year return period storm (Crawley and Cunnane, 2003).
- Multiplying the resulting values further by 20% (i.e., 1.2) to conservatively account for climate change (Crawley and Cunnane, 2003).

2.2 Runoff from Access Roads and Hardstand Areas

Runoff from access roads and hardstand areas will be captured by swales that are constructed downslope of all infrastructure components. The captured runoff water is led to settlement (stilling) ponds before being discharged to nearby streams. The swales and settlement ponds are particularly important for the construction phase but will also remain in place during all subsequent phases of the Proposed Development.

The runoff calculations for access roads and hardstand areas are based the 'Rational Method' (Mulvaney, 1851), which is represented by the following equation:

$$Q = c \times I \times A$$

where,

- Q = peak runoff rate (m^3/s).
- c = runoff coefficient - an empirical coefficient representing a relationship between rainfall and runoff.
- I = rainfall intensity for the design return period (mm/hr).
- A = subcatchment area (m^2)

The calculation considered a 6-hour duration, 1 in 10 year return period storm. The duration of construction of the Proposed Development is 2 years (maximum), and a 1 in 10 year storm event can reasonably be expected to occur during the construction period.

2.3 Sizing of Settlement Ponds

The sizing of settlement ponds is based on the following equation:

$$A = Q/Vs$$

Where:

- A = area of pond (m^2)
- Q = flow into pond (m^3/s), from Section 2.2 above.

- Vs = settling velocity (m/s) of fine silt-grade particles, selected to be 10 µm (0.01 mm) in size, reflecting the need to settle out fines.

Vs is calculated from Stoke's Law:

$$Vs = [2 \times r^2 \times g \times (D_p - D_f)] / (9\ n)$$

Where,

- r is the radius of the particle (m)
- g is gravity (9.80665 m/s^2)
- D_p is the density of the particles (kg/m^3), taken to be 2,400 kg/m^3
- D_f is the density of the fluid (kg/m^3), taken to be 1,000 kg/m^3
- n is the dynamic viscosity of the fluid (0.001308 kg/ m sec @ 10°C)

Hence, for a 10 µm particle, Vs = 0.000234 m/s (or 20.21 m/d).

2.4 Flows to Guide the Sizing of Culverts

The high rainfall amounts and steep slopes in parts of the Proposed Development site requires that pipe culverts and water crossing structures be oversized in a subsequent design phase in order to mitigate the potential for causing damage to access roads and excessive erosion. Hence, conservative runoff volumes were estimated based on the publication "Drainage of Runoff from Natural Catchments" published by Transport Infrastructure Ireland (TII, 2015), whereby Q_{bar} was adjusted up for design storms with a return period of 75 years, accounting for:

- The revised national growth curve for Ireland of approximately 1.77 for a 75-year storm event (average of 1 in 50 and 1 in 100 year storm values, per Cawley and Cunnane, 2003).
- The standard factorial error (SFE) of 1.65, per method IH 124, for culvert designs.
- A 20% increase to Q_{bar} values (adjusted), to account for climate change.

3. Results

3.1 Greenfield Runoff

3.1.1 Q_{bar}

The runoff calculations from greenfield subcatchments are presented in **Table 1**. Calculated Q_{bar} values for the different subcatchments range from 0.004 to 0.62 m^3/s, for a sum of 9.884 m^3/s. Adjusted up to account for 1 in 10 year design floods and climate change, the adjusted Q_{bar} values range from 0.006 to 1.105 m^3/s, for a sum of 16.021 m^3/s.

Table 1: Calculated Greenfield Runoff Rates

Subcatchment	Area (m^2)	Q_{bar}, per IH 124 (m^3/s)	Q_{bar}, Adjusted (m^3/s)
A1	102,663.42	0.130	0.211
A2	13,419.88	0.022	0.036
A3	20,345.73	0.031	0.050
A4	72,632.47	0.096	0.156
A5	24,538.94	0.037	0.060
A6	110,088.80	0.138	0.224
A7	159,805.90	0.193	0.313
A8	89,012.66	0.115	0.186
A9	212,022.67	0.248	0.402
A10	55,001.70	0.075	0.122

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Subcatchment	Area (m^2)	Q_{bar}, per IH 124 (m^3/s)	Q_{bar}, Adjusted (m^3/s)
A11	82,270.42	0.107	0.173
A12	318,067.71	0.355	0.575
A13	662,680.87	0.682	1.105
A14	116,281.49	0.145	0.235
A15	452,958.16	0.486	0.787
A16	495,845.52	0.527	0.854
A17	312,025.10	0.349	0.565
A18	180,989.52	0.215	0.348
A19	203,980.40	0.239	0.387
A20	238,800.52	0.275	0.446
A21	77,098.97	0.101	0.164
A22	104,300.28	0.132	0.214
A23	1,863.23	0.004	0.006
A24	78,489.29	0.103	0.167
A25	44,349.71	0.062	0.100
A26	25,496.38	0.038	0.062
A27	123,365.20	0.153	0.248
A28	28,073.42	0.041	0.066
A29	165,881.22	0.199	0.322
A30	88,477.41	0.114	0.185
A31	240,094.76	0.277	0.449
A32	38,707.33	0.055	0.089
A33	101,628.35	0.129	0.209
A34	69,661.88	0.092	0.149
A35	356,727.12	0.393	0.637
A36	6,507.39	0.012	0.019
A37	6,658.40	0.012	0.019
A38	6,903.92	0.012	0.019
A39	296,647.77	0.334	0.541
A40	29,097.98	0.043	0.070
A41	15,347.07	0.024	0.039
A42	215,303.68	0.251	0.407
A43	43,930.95	0.061	0.099
A44	77,115.88	0.101	0.164
A45	138,704.84	0.170	0.275
A46	25,218.16	0.038	0.062
A47	34,385.05	0.049	0.079
A48	11,551.47	0.019	0.031
A49	9,395.60	0.016	0.026
A50	90,792.75	0.117	0.190
A51	30,125.31	0.044	0.071
Sum	**6,505,332.65**	**7.661**	**12.411**

3.1.2 Q_{med}

As a cross-check on Q_{bar} in **Table 1** (sum 7.661 m^3/s for an area of 6.5 km^2), the value of 'Q_{med}' was calculated using the web portal of OPW's Flood Studies Update (FSU) Programme.[2] Q_{med} is an annual *median* flood index, defined as the *"flood that is exceeded on average every other year"*[3]. The calculation of Q_{med} method is relevant as it incorporates a wider range of catchment characteristics.

For the catchment area of the Altderg River shown in **Figure 2**, which covers an area of 10.03 km^2, the calculated Q_{med} value is 7.25 m^3/s (rounded). Compared to Q_{bar}, this produces a higher specific runoff, as indicated in **Table 2**.

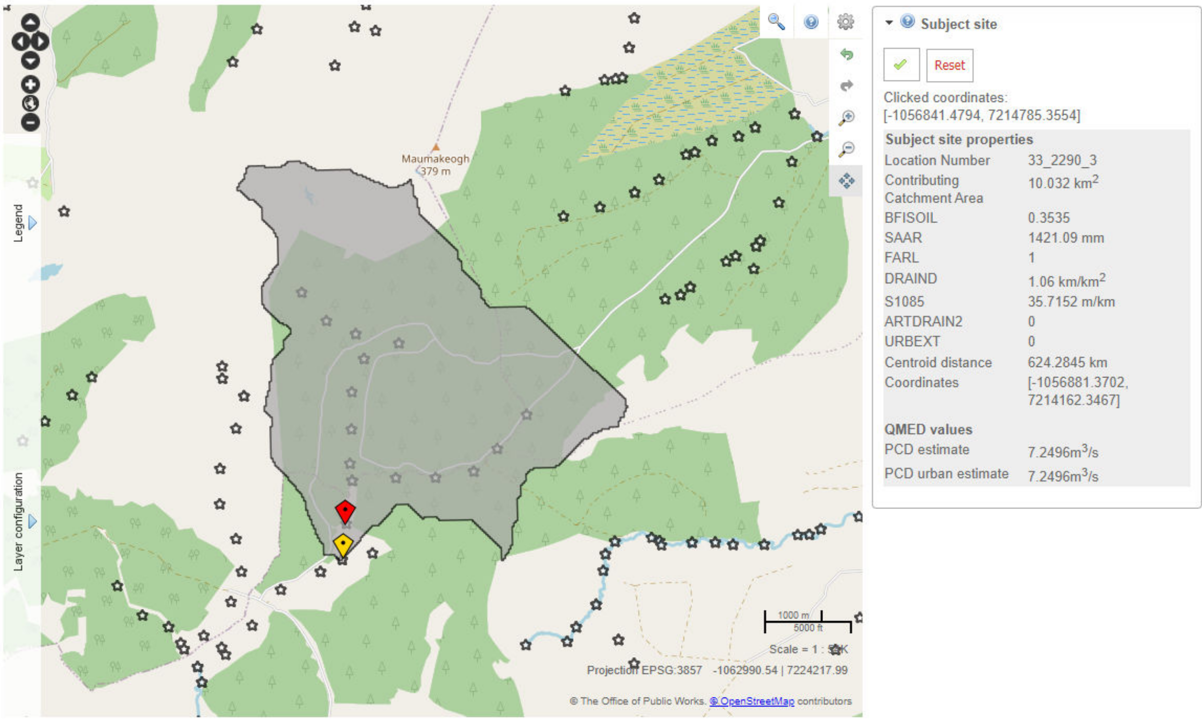

Figure 2: Output, Q_{med} Calculation, Per OPW's FSU Web Portal

Table 2: Specific Runoff from Values of Q_{bar} and Q_{med}

	Area (km^2)	Calculated Value (m^3/s)	Specific Runoff ($m^3/s/km^2$)
Q_{bar}	6.50	7.661	1.18
Q_{med}	10.03	7.249	0.74

The difference is attributed to the areas applied and the value of SAAR. The SAAR value used by the FSU webportal is 1,421 mm/yr (Figure 2) which is considerably lower than the 1,850 mm/yr long average annual rainfall at Glenora Forest. It would, therefore, appear that the Q_{med} value may underestimates median flood flow in this instance.

[2] https://opw.hydronet.com/

[3] https://www.ceh.ac.uk/services/flood-estimation-handbook

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For an average specific runoff value of 0.96 $m^3/s/km^2$ (average of the two values in **Table 2**), the estimated index flood for the subcatchments of the proposed infrastructure area of 6.5 km^2 becomes 6.24 m^3/s. The equivalent 1 in 10 year design flood across Glenora Forest, accounting for climate change, becomes 10.11 m^3/s.

3.2 Runoff From Access Roads and Hardstand Areas

Based on Chapter 9 of the EIAR, the rainfall depth for the 6-hour duration, 10-year return period storm event is 43.2 mm, which equates to a rainfall intensity of 7.2 mm/hr.

For access roads and hardstand areas (which are not paved), a runoff coefficient of 0.7 was used (i.e., relatively impermeable). Thus:

$$Q = 0.7 \times [(7.2/1{,}000)/3{,}600] \times 1 = 1.4\times10^{-6}\ m^3/s \text{ per unit area (one } m^2\text{)}.$$

The value of Q was subsequently applied to the construction areas of different infrastructure components, as presented in **Table 3**.

Table 3: Calculated Runoff From Access Tracks and Hardstand Areas

Item	Construction Area (m^2)	Runoff Generated (m^3/s) - Rounded
Hardstand and Crane Pads for Turbines	106,990	0.150
New Access Tracks[1]	86,940	0.122
Existing Access Tracks to be Upgraded[1]	94,265	0.132
Construction Compounds[2]	15,420	0.022
Electrical Substation	21,495	0.030
Borrow Pits[3]	93,605	0.0131
Met Mast Platform	295	0.0004
Sum	**419,010**	**0.587**

Notes:
[1] Five metre running surface with six metre wide development footprint.
[2] Total for 5 no. compounds of equal size.
[3] Total for 3 no. pits.

3.3 Estimated Sizing of Settlement Ponds

To be able to settle out particles of 10 µm, pond area requirements are calculated from:

$$\text{Area} = Q/V_s$$

Where,

Q = the flow rate into the pond (m^3/s).
Vs = settling velocity of particles of 10 µm based on Stoke's Law = 0.000234 m/s.

Results of total pond area requirements for each component of the Proposed Development are presented in **Table 4**.

Table 4: Calculated Pond Area Requirements To Settle Out 10 µm Particles

Item	Runoff Generated (m^3/s) - Rounded	Pond Area Required (m^2) – Rounded
Hardstand and Crane Pads for Turbines	0.150	640
New Access Tracks	0.122	520
Existing Access Tracks to be Upgraded[1]	0.132	564
Construction Compounds[2]	0.022	93
Electrical Substation	0.030	129
Borrow Pits	0.0131	560
Met Mast Platform	0.0004	1.8
Sum	**271,863**	**2,508**

There are 22 no. turbines, which means that the size of settlement ponds at each turbine site will need to be 29 m^2 on average. The single largest pond requirement is for the Borrow Pits (3 no.), which require a total area of 560 m^2, or 280 m^2 as an average. The new and existing access road upgrades require a total pond area of 1,084 m^2, across a total length of 28.5 km, which equates to 38 m^2 per km length of access tracks.

Practically, the construction of individual ponds should be limited to areas of 20 to 30 m^2, based on dimensions on the order of 3×7 m to 3×10 m, and a pond depth of 1 m. The calculations above demonstrate that construction of ponds of a practical size and number is feasible. For access tracks, the requirement becomes 2 no. ponds per km on average. The electrical substation will require up to 5 ponds, and presents the main construction challenge to accommodate drainage needs.

3.4 Estimated Flows to Guide the Sizing of Culverts

As presented in Chapter 9 of the EIAR and depicted in **Appendix 4-4**, the proposed infrastructure within the Wind Farm Site will require the upgrade and construction of new, piped culverts to accommodate the preliminary, proposed drainage layout. Existing pipe culverts range in diameter from 300 to 600 mm. To confirm culvert sizing, calculations of design floods were made and compared against the flow capacities of plastic/HDPE and concrete pipe materials.

Contributing subcatchment areas of culverts range in size from <0.001 to 0.394 km^2. Resulting adjusted Q_{bar} values for culvert subcatchments range from 0.011 to 1.507 m^3/s.

Assuming 10 m average lengths of culverts and a 0.5 m head drop across culverts, calculated flow capacities of PVC/HDPE and concrete pipes are summarised in **Table 6**. Based on the maximum adjusted Q_{bar} value of 1.507 m^3/s, the maximum pipe diameter that will be needed to accommodate the indicative 1 in 100 year design flow is 600 mm for PVC/HDPE and 900 mm for concrete pipes (as the maximum capacity for 600 mm pipe is close to the calculated flow). These estimates do not factor in potential flow velocity constraints or potential scour effects which will have to be considered during actual design of any given culvert.

Table 6: Calculated Pipe Flow Capacities (Gravity Flow) for Different Diameter Pipes

	Calculated Flow Capacity (m^3/s)[1]	
Pipe Diameter (mm)	Plastic/HDPE[2]	Concrete[3]
300	0.349	0.256
450	1.014	0.744
600	2.16	1.585

900	6.28	4.605
1200	13.38	9.81

Notes:
[1] Per Hazen-Williams Equation for velocity
[2] Roughness coefficient = 150
[3] Roughness coefficient = 110

4. References

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