Oban Flood Study
Report 3B: Options Appraisal - Economic Appraisal

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Executive Summary

Economic appraisal of short-listed options has been conducted using standard Flooding and Coastal Erosion Risk Management Multi-Coloured Handbook ("MCH") techniques and in compliance with Scottish Government options appraisal guidance in relation to flood risk management. Option development for each source of flooding has been assessed separately, with this supported by limited overlap in predicted damages from each flooding source, as well as predicted lack of detrimental interaction between options targeting one source of flooding upon other sources of flooding.

Fluvial (Including Tidal) Flood Risk Management

In the absence of new capital flood management investment, damages due to flooding from the Black Lynn watercourse system (including Glenshellach Burn, Soroba Burn and Alltan Tartach, and inclusive of tidal flooding in the Black Lynn) are estimated at £17.9 million over the following 100 years (in Present Value terms, based on a 2019 cost date). Commercial and public carparking in the Lochavullin area is predicted to be at risk of flooding for the smallest event considered in analysis (the 1 in 2 year return period event), with non-residential buildings in the area at risk from the 1 in 5 year return period event and residential properties in the Miller Road area at risk (due to overtopping of the Miller Road culvert inlet) from flooding exceeding a 1 in 5 year return period.

The following options are recommended for further consideration, design and optimisation as part of a strategy for managing fluvial flood risk in Oban:

- Widening of the Market Street bridge and adjacent river section, in order to reduce the existing hydraulic bottleneck at this location, which is worsening flood risk in the Lochavullin area.
- Enhancing existing flood storage in the Lon Mor area, by raising of a flood bund and alteration to the existing culvert arrangement, to attenuate flows from the Glenshellach Burn, and thereby reduce flood risk in the downstream Soroba Burn and Black Lynn.
- Lowering a section of existing wall and raising a flood bund to preferentially flood the Mossfield Stadium area, thereby reducing flood risk downstream in the Alltan Tartach and Black Lynn, including reducing the risk of overtopping of the Miller Road culvert inlet.
- Raising new defence walls and embankments in the Black Lynn, particularly in the Lochavullin area, to achieve a minimum bank level in the Black Lynn of 4.0 metres above Ordnance Datum (only in combination with other options which address the risk this option creates of increasing flood risk elsewhere).
- Dualling the Miller Road culvert, to substantially reduce the risk of overtopping of the inlet of this culvert (only in combination with other options which address the risk this option creates of increasing flood risk elsewhere).

These options are shown, in combination (Option 5E), to be capable of reducing property-related damages over the next 100 years by up to 77% or £13.8 million at a whole life cost of £8.2 million (with capital cost element of £7.6 million), achieving an overall benefit-cost ratio of 1.68. Other benefits, including reduction in traffic-related damages (i.e. road closure and traffic diversion and delays due to flooding), reduction in loss of productivity (i.e. loss of access to workplaces due to road flooding), and reductions in the risk of injury and death due to flooding, may provide up to £9.6 million of additional benefit and improve the benefit-cost ratio of the preferred option to 2.84, although there are higher uncertainties associated with monetising of these benefits.

Within the area benefitting from the proposed scheme, this option combination is predicted to increase the minimum standard of flood protection for residential properties from 1 in 5 years (currently) to 1 in 50 years for existing climate conditions, with the minimum standard of protection for non-residential properties improved from less than 1 in 2 years to 1 in 100 years for existing climate conditions.

Coastal Flood Risk Management

Present Value damages associated with coastal flooding in Oban are estimated at £10.3 million over the next 100 years. An extensive coastal defence option has been examined and, while capable of significantly reducing coastal flood damages by approximately £4.9 million (over 100 years), the whole life cost of the proposed defences is predicted to exceed these benefits, such that the proposed option is not economically justifiable.

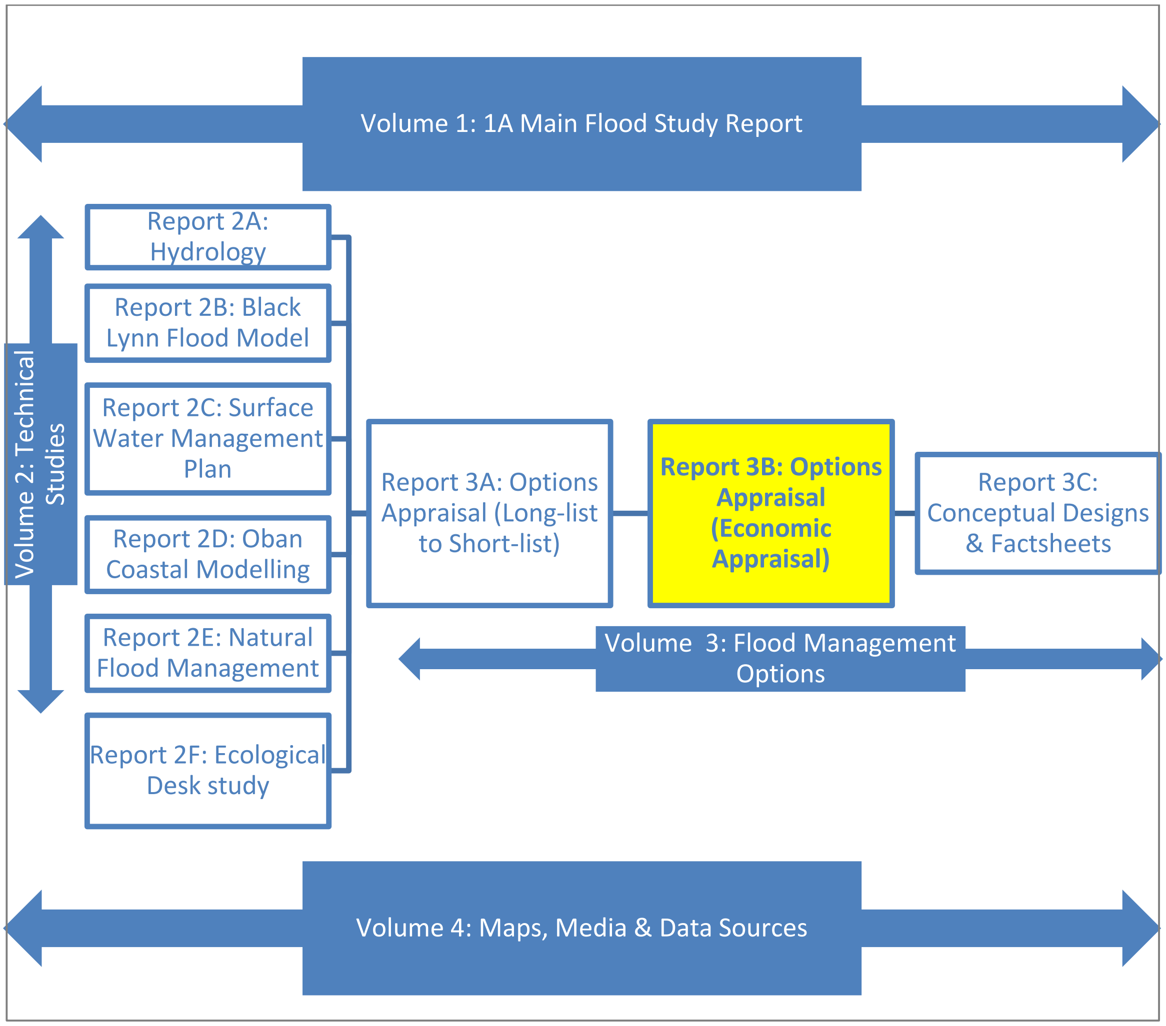
A more spatially-restricted option variant is capable of achieving most (£4.78 million) of this benefit at lower £3.89 million estimated whole life cost, and may therefore be cost-effective, but this is dependent upon confirming that new defences can be placed either on top of existing coastal defence walls or else between the walls and A85 road; if instead new defences need to be placed beyond the existing defensive walls, additional land reclamation costs will result in this option variant also being too expensive to justify. In this situation, it is recommended that further consideration of coastal flood defence is deferred, given the reasonable level of protection currently offered by existing defences and natural topography, with immediate investment instead made in providing property level protection to the small number of properties (on or north of the North Pier) that are at highest risk of coastal flooding.

Surface Water Flood Risk Management

High-level economic appraisal, based on the MCH Weighted Average Annual Damage (WAAD) approach and Scottish Water's sewer network model predictions for Oban, suggest that damages associated with surface water flooding amount to an estimated £3.0 million over the next 100 years. Given the low value of damages and the relatively high uncertainty in damage estimation for this source of flooding, no immediate investment is recommended or adequately justified to address this source of flood risk. Instead, it is recommended that surface water flood risk be managed, in collaboration with Scottish Water and other stakeholders, as part of a longer-term strategy as discussed in *Report 2C: Surface Water Management Plan*.

OBAN FLOOD STUDY REPORT MAP

The context of the current report within the wider Oban Flood Study is highlighted in yellow as shown below.



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1 INTRODUCTION

1.1 Terms of Reference

This economic appraisal of flood risk management options has been carried out as a key part of the Oban Flood Study, which has been commissioned by Argyll and Bute Council.

This report has been prepared within the context of the Oban Flood Study and should be read in conjunction with (*Report 1A: Main Report*).

1.2 Scope of Report

Investment for flood management should be supported by analysis demonstrating that proposed measures provide net benefits exceeding the net cost of their implementation and maintenance. This report presents the economic appraisal conducted in relation to short-listed options identified in *Report 3A: Options Appraisal*, aimed at identifying which options or option combinations are the most cost-effective at managing flood risk in Oban.

Reference should also be made to *Report 2B: Black Lynn Flood Modelling* and *Report 2D: Oban Coastal Modelling*, which detail the fluvial and coastal flood modelling underlying this economic appraisal. Fluvial and coastal flood maps are presented in *Volume 4: Maps, Media and Data Sources*. Conceptual drawings for short-listed options and the summary fact sheets for preferred option elements are both presented in *Report 3C: Conceptual Designs and Factsheets*.

1.3 Report Usage

This report has been prepared as part of the Oban Flood Study commissioned by Argyll and Bute Council and should not be used beyond this context without their permission.

It is important to note that the assessment has been prepared in the context of a catchment-scale flood study and as such is designed to assess flood risk at a strategic level. It is not intended for site-specific flood risk assessment purposes.

If this report is to be submitted for regulatory approval more than 12 months following the report date, it is recommended that it is referred to EnviroCentre Ltd for review to ensure that any relevant changes in data, best practice, guidance or legislation in the intervening period are integrated into an updated version of the report.

2 METHODOLOGY

2.1 Guidance

The Scottish Government has published option appraisal guidance[1] for flood risk management, as part of implementation of the Flood Risk Management (Scotland) Act 2009. Although the guidance is not intended to be prescriptive, it sets out the principles for conducting option appraisal to assist decision-making in relation to flood risk management. The guidance states that option appraisal should aim to achieve the following:

> Implementation of sustainable solutions, accounting for economic, social and environmental impacts, which protect and enhance the natural and built environment for ourselves and future generations.
> Demonstrate best use of public money, by ensuring that the proposed measures are cost-effective (generally in monetised terms, but also with consideration of unpriced benefits and costs).
> Demonstrate accountability, by ensuring that option appraisal is conducted with a clear audit trail and demonstrates that a wide range of options has been objectively considered.
> Demonstrate robustness, by reporting and giving consideration to all uncertainties, assumptions and limitations impacting the appraisal process, and testing the sensitivity of appraisal outcomes to these.

A proportionate approach should be used for options appraisal, depending upon the stage of the appraisal (i.e. less details for strategic and conceptual assessments and more detail appropriate as option design is approached), the magnitude of investment required (i.e. less detail needed where the economic risk is smaller), and the ability of the appraisal to clearly differentiate the performance of alternative flood management options (i.e. more detail needed where there are no clear preferred options).

2.2 Economic Appraisal Concepts

Economic appraisal entails a comparison of whole life cost (WLC) against whole life benefit (WLB), to determine whether a given option or strategy is cost-effective and therefore has a business case for investment (i.e. where WLB > WLC). Where there are multiple competing options, or limited funds for investment, it may be used more explicitly to determine the benefit-cost ratio (BCR) of one or more options, to allow options to be ranked and to be compared to alternative investments.

Economic appraisal involves the following concepts/definitions:

> 'Do Nothing' or 'Do Minimum' option: Economic appraisal of short-listed options must be conducted relative to a baseline, and either the 'do nothing' or 'do minimum' scenario is used as the baseline. The 'do nothing' option defines the 'walk away' scenario where any existing assets or flood risk management measures are no longer conducted/maintained, subject to statutory health and safety constraints (which may require some minimal spend to make abandoned works safe). Where there is a statutory duty to maintain certain assets or conduct certain works (such as the duty to provide surface water drainage, clear and repair damage to bodies of water, and provide civil protection), the 'do minimum' scenario may be a more appropriate baseline, accounting for the cost needed to maintain existing assets in their current condition.
> 'Do something' options: These are options which build on the chosen baseline and aim to reduce flood risk relative to the baseline, usually at some additional cost relative to the baseline.

[1] Scottish Government (2016). Option appraisal for flood risk management: Guidance to support SEPA and the responsible authorities.

Economic Appraisal Period: The period of time, from construction/implementation onwards, over which costs and benefits are considered. By default, this is usually 100 years, but may be lower in some situations, for example to equal the expected operational life of the longest-lived option being considered.

Present Value (PV): This concept refers to the discounting of future costs and benefits (beyond Year 0 in the economic appraisal period), to reflect the preference for deferring payments and receiving benefits sooner. Benefits or costs realised sooner therefore have greater weighting than benefits or costs realised at a much later point of the economic appraisal period.

Discount Rate: This is the rate at which the monetized value of costs and benefits is assumed to decay with time. The HM Treasury Green Book[2] recommends 3.5% annual discounting between years 0-30 of an economic appraisal, reducing to 3% between 31-75 years and to 2.5% between 76-125 years.

Whole Life Cost (WLC): This is the summation of all construction, operation and maintenance costs (in present value terms) over the economic appraisal period. Where some elements of the option have an operational life that is less than the economic appraisal period, this will include deferred capital costs to replace/reinstate those elements. Any wider adverse environmental or social impacts associated with a given option should also be considered.

Whole Life Benefit (WLB): Likewise, this is the summation of all monetized benefits (in present value terms) over the economic appraisal period. For flood risk management, the primary form of benefit is a reduction in flood-related direct and indirect damages, but may also include social and environmental benefits.

Benefit-Cost Ratio (BCR): Simply the ratio of WLB to WLC.

Incremental Benefit-Cost Ratio (IBCR): Where more than one option might be progressed, or when an option could be enhanced to provide additional benefit, it is usually required to assess the IBCR. Relative to some baseline option, this is the ratio of additional benefit against additional cost, with it usually being necessary to demonstrate a positive IBCR to justify additional spend to enhance or supplement the baseline option. For example, a 1m high flood defence wall may protect against the 1 in 30 year event at a cost £100k to construct and maintain over the economic appraisal period and deliver flood damage reduction benefits of £200k (i.e. a BCR of 2). Raising the wall by a further 0.5m may protect against the 1 in 50 year event with total cost of £150k and increased benefits of £220k; while the BCR of this "enhanced" option is 1.47, it's IBCR is 0.4, suggesting the additional spend is not cost-effective and the baseline option is preferable.

Economic appraisal is usually built around monetised benefit-cost appraisal, but in some instances it may not be possible or proportionate to monetise certain positive and negative impacts, risks or opportunities. In these situations, benefit-cost appraisal may be supplemented with multi-criteria analysis to allow comparative assessment of non-monetised impacts across competing options and hence allow options to be ranked.

2.3 Assessment of Benefits

The primary benefit of most flood management options will be a reduction in direct and indirect damages resulting from flooding events. Other forms of benefit may include:

Ecosystem services provision; for options (such as natural flood management, deculverting and certain SuDS types) which create new habitat or improve the quality of existing habitat.

Air quality and carbon sequestration benefits for options involving net increase in vegetation coverage.

Water quality benefits, for options which reduce the risk of polluted water reaching watercourses (conventional and sustainable sewer solutions, as well as options which prevent floodwater from inundating industrial areas or displacing foul drainage capacity within combined sewers).

[2] HM Treasury (2018). The Green Book. Central Government Guidance on Appraisal and Evaluation.

Amenity benefits (where green infrastructure measures improve the attractiveness and hence value of a given area).
Reduction in pumping and water treatment costs, for options which reduce the need for each.

If a given option is expected to produce substantial benefits of any of these types, consideration should be given to whether a monetized estimate could be included in the economic appraisal. This is only proportionate if:

these forms of benefits are substantial; and/or,
one or more options have a very similar business case based on flood damage otherwise, and these benefits could be used to help identify the best option; and/or
the preferred option has a marginal business case, and quantification of these benefits is essential to demonstrate or strengthen the case for investment.

2.3.1 Estimating Flood Damage Reduction Benefit

Flood damages may consist of multiple elements:

Direct damages to residential homes (material and contents) and likewise for commercial and industrial premises, which will vary depending upon the nature of the property, depth of flooding, the persistence of flooding, and whether the floodwater contains fouls or other dangerous pollutants. For the most part, quantification is partly simplified by classifications of property types (for example, detached, semi-detached, terraced and flats for residential properties) and the use of statistic depth-damage tables for each category of property and type of flooding.
Indirect damages, which may include emergency service response, damage to vehicles, temporary accommodation costs, time away from employment, and indirect health costs (or, conversely, indirect health benefits from reducing flooding).
Risk to life damage reduction, which is a potentially high-value form of benefit, if it can be demonstrated that an option reduces the exposure of populations (particularly vulnerable populations) to high-hazard flooding.
Traffic damages, if roads are flooded to a depth causing low speeds or road closure necessitating significant diversion.
Flooding causing closure or impaired access to important facilities (such as hospitals, transport hubs, schools/nurseries, major places of employment, etc.)
Loss of power, water or other public service or utility provision.

The Multi-Coloured Handbook (MCH) and Multi-Coloured Manual (MCM) provide extensive details on how to quantify these types of damages, with assessment of direct damages to properties in particular being well-developed. The process for determining direct flood damages for any given scenario (i.e. baseline as well as ‘do something’ flood management options) is as follows:

1. Conduct simulations for a full suite of return period events for each scenario. Typically, the suite should include low return period events (e.g. 1 in 2 or 1 in 5 year event) as well as “higher than design” events (such as the 1 in 500 or 1 in 1000 year event), and enough events in between to accurately estimate the average annual damages (AAD). This study examines the 1 in 2, 5, 10, 30, 50, 100, 200 and 1000 year return period events.
2. Repeat (1) for future climate change epochs over the economic appraisal period, in order to account for change in average annual damages. Further detail on the representation of climate change impacts upon flood risk is presented in *Report 2A: Hydrological Analysis*, *Report 2B: Black Lynn Flood Model* and *Report 2D: Oban Coastal Modelling.* On the basis of 2020 being Year 0 of the economic appraisal, this study explicitly models current climate conditions (i.e. for the year 2020), as well as the 2050 and 2100 climate change epochs for each scenario.

3. Use MCH damage tables/data to determine damages for each receptor for each return period and climate change epoch. The short-duration (<12 hour event duration) “no warning” storm damage tables are appropriate for fluvial appraisal for this study, and short-duration with-warning “with waves” damage tables are appropriate for coastal appraisal.
4. Use probability weighting to determine the AAD for each receptor for each epoch from individual event damage predictions. By linear interpolation (between 2050 and 2100) and extrapolation (beyond 2100), estimate the AAD for all years of the appraisal period.
5. Apply standard discounting to future AAD values and sum over the appraisal period to determine present value (PV) damages for each receptor and, by summation over all receptors, the total PV damages for the scenario.

Other forms of indirect damages associated with property flooding are also quantified using standard assumptions and methods; further details of these are provided in Section 2.5.

Economic comparison of options focusses on direct and indirect damages associated with property flooding; monetising of other forms of damages has a higher degree of uncertainty and is therefore only considered in supplementary analysis, in Sections 3.8 and 4.2.4. Except where explicitly clarified, therefore, whole life damage, whole life benefit and benefit-cost ratio values presented in this report relate to property flooding only.

2.3.2 Property Categorisation

Residential and non-residential property location and attribute data was provided by Argyll and Bute Council. All data was processed to determine the appropriate MCM property classification, which corresponds to a given depth-damage dataset; Table 2.1 summarises all categories identified from the provided dataset.

Table 2.1: MCM property categories for the Oban area

MCM (2019) Code	Sector	Description
2	Non-Residential	Retail (shops, showrooms)
3	Non-Residential	Offices (incl. banks, studios and other commercial offices)
4	Non-Residential	Distribution/logistics (incl. warehouses, storerooms, depots)
6	Non-Residential	Public buildings (incl. care homes, village halls, libraries, medical surgeries, schools/nurseries/universities, places of worship, etc.)
8	Non-Residential	Industrial (workshops, factories, manufactories)
11	Residential	Detached properties
12	Residential	Semi-detached properties
13	Residential	Terrace properties
15	Residential	Flats
51	Non-Residential	Hotels, hostels and guest houses
521	Non-Residential	Sporting grounds and playing fields
910	Non-Residential	Car parks (incl. coach parking and park and ride)

2.3.3 Determination of Non-Residential Property Area

Non-residential damages are proportional to the floor area of the property. Provided property data generally did not include an area attribute, such that property area needed to be estimated by joining this data to the OS Mastermap building polygon in which the data point is contained (using Geographic Information System, or GIS, techniques). As some buildings contain more than 1 receptor point, it was thereafter necessary to manually assess each such building using available street-level photography and Scottish Assessors Association property data (see Section 2.3.6) to estimate division of total building area between individual receptor points.

2.3.4 Removal of Upper Floor Receptors

Oban contains many multi-storey buildings, with the property data including all individual flats and offices located above the ground floor. With exception of the Lochavullin coach and car park, predicted flooding depths (even for the worst event considered in analysis; the 1 in 1000 year event for 2100 climate change conditions) are less than 2 m for all receptors, such that it is reasonable to exclude all properties not located on the ground floor from economic appraisal. All building polygons containing more than 1 receptor point were manually assessed using available street-level photography and attribute data, and these additional data points were removed from the receptor dataset (noting that some buildings legitimately contain 2 or more ground-level receptors, in which case these are retained).

2.3.5 Building Upstand

Selected buildings, identified as being at high risk of fluvial flooding during preliminary appraisal, were subject to threshold surveying. The LiDAR DTM ground model has been modified to create a horizontal "floor" equal to the surveyed threshold level for these buildings. Based on a comparison of threshold survey values against LiDAR ground levels, the average upstand (excluding outliers) for surveyed buildings was estimated at approximately 300 mm. For all buildings not surveyed, an assumed upstand of 300 mm has therefore been applied, using EA (2013)[3] methodology, which is based on the mean, standard deviation and maximum DTM ground level values within the building footprint:

$$Z_{upstand} = Min\left(\left(\bar{Z}_{building} + 2\sigma + 0.3\right), \left(Max\left(Z_{building}\right) + 0.3\right)\right)$$

Where:

$Z_{upstand}$ = new height applied to all grid cells within a given building footprint

$\bar{Z}_{building}$ = mean of all "bare earth" heights within a given building footprint

σ = standard deviation of all "bare earth" heights within a given building footprint

$Z_{building}$ = set of "bare earth" heights within a given building footprint

2.3.6 Damage Capping

If the predicted whole life PV damage for a given property exceeds the market value of the property, it will usually be written off by insurance, rather than continuing to be repaired or rebuilt after each flood instance. To reflect this, total PV damages for each individual property over the appraisal period should be capped at the market value. For residential properties, market values have been taken from January 2019 values provided with the MCH for Scotland (Table 2.2).

For commercial properties, it is necessary to estimate market values from rateable values and yield information available on the Scottish Assessors Association website (https://www.saa.gov.uk/), or else through site-specific assessment in discussion with the business owner. The market value of non-residential properties is determined by multiplying the rateable value of the property (£/m^2) by the floor area of the property (m^2) and dividing this value by the yield (%). The market value of specific properties at high flood risk has been determined based on site-specific listings and average yields provided by the MCH (Table 2.3).

[3] Environment Agency (2013). Updated Flood Map for Surface Water. National Scale Surface Water Flood Mapping Methodology.

Table 2.2: Residential damage capping – average house price values by housing type for Scotland (January 2019)

Property Type	Average House Price
Detached	£256,726
Semi-detached	£155,010
Terrace	£123,475
Flat	£107,872

With no rateable value statistics being available for Oban, the market value for all other non-residential properties has been estimated based on:

an assumed yield of 5.75% (determined for Glasgow; Savills, 2016[4]); and
an assumed rateable value of £75/m² (below the £80/m² average for England and Wales, noting that a corresponding average value is not available for Scotland) for all non-residential buildings; and
an assumed rateable value of £25/m² for car parking areas.

Table 2.3: Estimated market value for specified non-residential properties

Property Name/Address	SAA Listed Rate (£/m²)	Floor Area (m²)	Yield	Estimated Market Value
Tesco Stores Ltd, Lochavullin Drive, Oban PA34 4BW	£152.75	5,230.81	5.25% (shopping centre)	£15,219,048
Lidl, Soroba Road, Oban PA34 4HY	£149.20	2,292.22	5.25% (shopping centre)	£6,514,286
Unit 1, Mill Lane, Oban PA34 4HA	£88.89	464.07	4.00% (industrial)	£1,031,250
Franks DIY And Autos, Soroba Lane, Oban	£25 (unlisted; assumed value)	504.55	5.75% (Glasgow average)	£222,609

2.4 Costing

Determination of whole life cost requires estimation of the following cost elements:

Construction costs: Capital costs realised during construction/implementation of the option, including disposal of spoil material where applicable. This will usually be based on a Bill of Quantities (BoQ) cost (from Spon's[5]/CESMM[6], etc.), with various uplifts applied relating to additional activities necessary prior to or during construction not accounted for in the BoQ (e.g. ground and site investigation, site supervision and project management/administration, cost consultancy, site setup and demobilisation, etc.). These costs will usually be realised in Year 0 of the economic appraisal period, but for large-scale works may require phasing of costs over the first few years to reflect the construction timetable.

[4] Savills (2016). Research article: Scottish office market. (https://www.savills.co.uk/research_articles/229130/210322-0)
[5] AECOM (2019). Spon's Civil Engineering and Highway Works Price Book.
[6] The Institution of Civil Engineers (2019). CESMM4 Revised: Civil Engineering Standard Method of Measurement.

Operational and maintenance costs: Estimated costs associated with inspecting and maintaining the option to ensure its effectiveness in flood management remains consistent over the appraisal period. For active elements, such as pumps, automated barriers and associated telemetry, this would include operational costs. These costs may be annual or periodic.
Where elements of an option have a shorter operational life than the economic appraisal period, whole life costs should make allowance for additional delayed capital investment that would be required to restore the operational life of the element(s) in question over the economic appraisal period (for example, most SuDS type options require major capital investment to be "rejuvenated" after a period of 20-50 years, at a cost of between 25-50% of the initial capital cost).

The following standard uplifts are applied to BoQ cost totals for all options considered in this study, unless otherwise noted:

10% uplift for preliminaries (including traffic management and insurance).
10% uplift allowance for minor service diversions.
15% uplift for site investigation and enabling works.
20% uplift to account for detailed design and project management costs.

2.4.1 Cost Date

Prices, and currency values, change with time. Unless all sourced monetized values (costs and benefits) are derived at a suitable recent time, consideration should be given to applying the necessary correction to bring values which were derived at an earlier date "up to date", such that the economic appraisal employs a common "cost date" (usually corresponding to Year 0 of the economic appraisal period) for monetising all costs and benefits in Present Value terms. Correction is normally performed based on the assumption that costs rise at the same rate as the New Infrastructure Output Price Index (OPI), and therefore by scaling by the ratio of the OPI at the intended common cost date to the OPI at the source cost date, noting that since 2015 the average annual increase in the New Infrastructure OPI is less than 2%, such that cost correction is usually only critical to option appraisal when business cases are marginal (i.e. BCR close to 1) or source prices are very old.

This study utilises the latest available (2019) MCH flood damage table data, with the majority of item costs obtained from the latest (2019) Spon's price book, and therefore do not require correction. Costs derived from older sources are corrected by scaling the latest available New Infrastructure OPI (110.8 for June 2019) against the corresponding index value for the source cost date.

2.4.2 Risk Contingency and Optimism Bias

Particularly at the early stages of design, there are many uncertainties and risks associated with costing, with a human tendency for costing to be optimistic with respect to these risks and unknowns. Economic appraisal therefore commonly employs an optimism bias to upscale all cost elements and provide some confidence in the business case for investment.

Typically, at outline design, an optimism bias of 44% may be assumed at the outline assessment stage for standard civil engineering works, however a higher value of up to 66% may be more appropriate for non-standard works or for works in heavily constrained or high risk locations[7]. As design progresses, known information about the site and ground conditions may improve confidence in the design, agreement may be reached between all stakeholders, design risks may be identified and mitigated, consents/approvals and public "buy-in" may be achieved, and procurement issues may be resolved, all of which reduce the uncertainty

[7] HM Treasury (2018). The Green Book. Central Government Guidance on Appraisal and Evaluation.

associated with the final design and its cost. As such, at progressively more detailed stages of design, the optimism bias would be expected to reduce.

By the detailed design stage, it would be expected that initially high optimism bias would be replaced with:

- A site- and design-specific assessment of risk, considering the probability of each risk being realised and the consequence to cost (and usually to construction works duration), would replace the majority of the optimism bias.
- However, a residual optimism bias is always expected to remain, to reflect uncertainties and risks which are beyond the ability of the designers to predict or mitigate, such as the risk of economic changes (currency value changes, material cost changes, wage changes, general industry changes), changes to policy and regulations, changing political pressures, etc. Usually, a residual optimism bias of 3-5% would therefore still be applied even for a detailed design with site- and design-specific risk contingency costing.

For the purpose of this economic appraisal, a standard optimism bias of 60% is applied to all costs for all options, reflecting that the proposed options contain both standard and non-standard civil engineering works within an urban-suburban area. Optimism bias is applied to the total estimated capital cost (i.e. BoQ cost, inclusive of all uplifts and additional general item costs), and is also applied to any operational/maintenance costs over the economic appraisal period.

Cost summaries for all options examined in the economic appraisal are presented in Appendix A.

2.5 Economic Appraisal Tools and Assumptions

Economic appraisal for this study makes use of the Damage Calculator tool packaged within Flood Modeller Version 4.5. The tool utilises the following data to derive PV whole life damages for individual receptors:

- A receptor point data set, containing all information needed to estimate damages for each receptor, including spatial coordinates, MCM code (based on the property type and usage), floor area (for non-residential receptors), market value (for damage capping), and address/identifier attributes.
- A series of flood depth maps, for a range of return periods and epochs (see Section 2.3.1).
- Depth-damage curve data, supplied with the 2019 MCH. For fluvial flooding, short-duration “no warning” storm damage curves have been used. For coastal flooding, short-duration “with warning” wave damage curves have been used.
- An appraisal period of 100 years is used, with linear interpolation/extrapolation used to determine AAD for years between and beyond the modelled 2020, 2050 and 2100 epochs.
- Vehicle damage is parameterised using the standard ownership ratio (1.15 vehicles per residential property) and value (£3,100 per vehicle), with a flooding threshold of 0.05 m used to account for the fact that building upstand (typically 300 mm for residential properties) is implicitly represented in the modified ground model used for flood modelling.
- All other default values have been retained (i.e. assumed 3% indirect damage uplift to non-residential property damage, 5.6% emergency response uplift to all property damage, with inclusion of evacuation-relocation costs based on “mid” values from 2019 MCH tables).

A tailored version of the Flood and Coastal Erosion Risk Management (FCERM) Economic Appraisal Spreadsheet (EA, 2010) is utilised for tabulating Damage Calculator output and combining this with estimated capital and maintenance costs, with optimism bias, to determine benefit-cost ratios for short-listed options and option combinations. The Damage Calculator tool does not determine the monetised intangible health benefit associated with improving the standard of protection against flooding to homeowners; this benefit is therefore calculated separately based on the MCH 2019 intangible benefits table (with interpolation used to estimate values for return periods not in the table, and discounting and summation performed to convert annual values in the table to PV values over the appraisal period) for all residential properties currently at flood risk.

2.6 Multi-Source Flood Risk

Economic appraisal and option development are conducted separately for coastal flooding and for fluvial flooding in this study, due to the separate nature of modelling and analysis used for each type of flooding:

- Flooding which occurs via watercourses, through either extreme tidal levels or extreme fluvial flows or a combination of both, is considered to be fluvial flooding for this purpose, primarily due to the fact that this form of flooding can only be managed by options which are implemented along the river (and, conversely, due to the fact that tidal flooding via the river will continue to pose a flood risk even if the coast is fully protected from direct flooding). Economic appraisal with respect to this flooding mechanism considered in Section 3.
- Flooding which occurs directly from overtopping of coastal defence/natural ground levels, via extreme sea levels or extreme wave heights or a combination of both, is considered to be coastal flooding for this purpose, with economic appraisal with respect to this flooding mechanism considered in Section 4.

There is some overlap between these two mechanisms in the area of Aird's Crescent and Stevenson Street, where flooding occurs due to direct connection to coastal flooding as well as overtopping of local existing river defences, however analysis confirms that such overlap only applies for events exceeding the 1 in 50 year event for the 2100 climate change epoch, and therefore has a very minor impact upon economic appraisal, noting:

- Analysis indicates that properties within the overlapping area contribute less than 1% to the overall baseline flood damages values for fluvial flooding, with the impact of coastal-fluvial overlap only for events exceeding the 1 in 50 year (2100) event being much less than this.
- For coastal option assessment, no benefit is claimed for properties within this area by ensuring that these areas continue to flood (as per baseline) even with the proposed coastal defence option in place.

A separate, high-level economic appraisal of surface water flooding is conducted based on existing predictions, noting that surface water flooding is regarded to be a comparatively minor source of overall property flood risk to Oban. This is presented in Section 5. While areas at risk from predicted surface water flooding overlap with those at risk of fluvial flooding (particularly in the Lochavullin area and around Miller Road) and coastal flooding (particularly between North Pier and Breadalbane Street), interaction between flooding from these mechanisms is not explicitly considered as part of this analysis due to the lack of an available network model for use in this study. Instead, a qualitative assessment of the potential impact of interaction of multi-source flooding is presented in Section 6.

3 ECONOMIC APPRAISAL OF FLUVIAL FLOOD MANAGEMENT OPTIONS

3.1 Assumptions

The following assumptions have been made for the purposes of this economic appraisal:

1. Assessment against a “do nothing” baseline is considered to be inappropriate and unreasonably complex and highly uncertain, as this scenario would be sensitive to assumptions regarding the current structural condition and rate of degradation and blockage of culverts, decay and collapse of existing defensive walls and embankments, for which limited or no site-specific information exists.
2. Instead, all assessment is made against a “do minimum” baseline representing maintenance of the current conditions of the river system and associated assets over the economic appraisal period of 100 years; all culverts are assumed to remain unblocked as per current conditions (which may require periodic and responsive clearance of culverts and trash screens), all existing informal defences (which include the walls of buildings built against the river edge in the lower Black Lynn) are assumed to be capable of withstanding extreme high water levels without damage or collapse, the bed profile and river cross-section is assumed to be unchanged (which may require periodic dredging and bank repair, and ignores the possibility of morphological changes in natural sections of the river).
3. While maintenance of the current conditions has an associated cost, these costs have not been estimated as part of this appraisal, with all option costs therefore being relative to the baseline cost (on the assumption that the cost of maintaining existing assets does not vary significantly according to which option or options are progressed). Maintenance costs for proposed options are considered as additional costs, with none of the proposed options anticipated to reduce maintenance costs associated with maintaining the current condition of the river system and associated assets. As such, these baseline maintenance costs are neutral for the purpose of economic appraisal, and this assumption will therefore have no impact upon the assessment of options.
4. An inherent assumption of economic appraisal is that no substantial change to catchment management takes place over the economic appraisal period, such as significant changes in land usage over relatively large areas (which may alter the hydrological response to storms relative to the assumed design response), creation or decommissioning of reservoirs or other impoundments in the upper catchment, or alterations to river route, capacity or in-channel structures. This includes the assumption that no measures which would amount to natural flood management are progressed, excepting as an explicit flood management option (see Section 3.6.10).

3.2 Determination of the Critical Duration Event

The hydrological critical duration event, producing the highest predicted design flow peak for the Black Lynn catchment, is estimated as a 3 hour duration event for the Revitalised Flood Hydrograph (ReFH2) design flow method. However, worst-case flooding may be caused by cumulative out-of-bank flow over a prolonged period of time, rather than by very high but temporary peak flowrates. In addition, attenuation due to culverts and other structures as well as out-of-bank flow can significantly alter the effective flow hydrograph further downstream in the catchment relative to the design inflow hydrograph. Economic appraisal should be based on the storm event duration which produces worst-case flood damages, and therefore it is necessary to examine the flood damage response to a range of return periods to determine the appropriate critical event duration for use in economic appraisal.

The baseline model scenario was run for both a low (1 in 5 year) and high (1 in 200 year) return period event over a range of storm event durations (see Section 3.3), and predicted damages determined for each run (Table

3.1). This analysis demonstrates that the 9 hour event duration is critical in terms of flood damages for both of the assessed return periods; it can be reasonably inferred that the same event will be critical for other return periods of interest, and is therefore the most appropriate event duration to use for economic appraisal in this study.

Table 3.1: Predicted flood damages for a range of storm event durations, for both the 1 in 5 year and 1 in 200 year return period events (maximum values shown in bold)

Flood Event	3 hrs	6 hrs	9 hrs	12 hrs	24 hrs	48 hrs
1 in 5 year	£93,940	£141,439	**£142,577**	£134,606	£93,926	£47,561
1 in 200 year	£3,355,076	£5,454,832	**£5,750,147**	£5,639,047	£3,784,007	£1,456,886

3.3 Design Event Details

3.3.1 Joint Probability Realisations

Preliminary analysis indicated that extreme fluvial conditions produce more extensive flooding at all locations than extreme tidal conditions for current climate change conditions, with very minor exceptions at the highest (1 in 1000 year) return period used in analysis. However, accounting for increased sea levels due to climate change (as well as increased fluvial flows), tidally-dominant conditions become increasingly important at progressively lower return periods for assessing worst-case flooding in the lower reaches of the modelled watercourse system. Therefore, for any given return period (and event duration; see Section 3.1), flood extents and flood damages are estimated by simulating both a fluvially-dominant joint probability realisation and a tidally-dominant joint probability realisation, and overlaying resultant flood maps to determine the maximum predicted flood depth at each location for the two realisations.

There is no data to allow the degree of statistical correlation between extreme tidal levels/sea levels and extreme fluvial flows to be established. Conservatively, analysis therefore assumes a high degree of correlation (=0.13), with Table 3.2 and Table 3.3 summarising the marginal return periods for fluvially-dominant and tidally-dominant joint probability realisations, respectively, based on the spreadsheet tool accompanying Defra/Environment Agency joint probability best practice guidance (FD2308; 2006). Table 3.4 details the corresponding peak tidal water level for each marginal return period for each climate change epoch.

Table 3.5 presents the peak inflow rate for each model inflow point for each marginal return period for the 9 hour critical duration event, noting that tabulated inflows for the Soroba Burn are unattenuated values; 66% of this total (representing the Soroba Burn catchment area downstream of Loch Gleann a Bhearraidh) enters the model without attenuation, while the remaining 34% (representing the catchment area upstream of Loch Gleann a Bhearraidh) is processed through a reservoir attenuation algorithm and added to the unattenuated element at the upstream boundary of the Soroba Burn (model node SB_016).

Table 3.2: Joint probability combinations for fluvially-dominant events

Overall Return Period (yrs)	Fluvial Return Period (yrs)	Tidal Return Period (yrs), (=0.13)
2	2	0.034
5	5	0.085
10	10	0.169
30	30	0.507
50	50	0.845
100	100	1.69
200	200	3.38
1000	1000	16.90

Table 3.3: Joint probability combinations for tidally-dominant events

Overall Return Period (yrs)	Fluvial Return Period (yrs)	Tidal Return Period (yrs), (=0.13)
2	1	0.068
5	1	0.423
10	1	1.69
30	1	15.21
50	1	42.25
100	1	100
200	1	200
1000	1	1000

Table 3.4: Peak tidal water levels for each marginal return period used in modelling, for current climate conditions as well as 2050 and 2100 epochs (in mAOD)

Marginal Return Period (yrs)	Current Epoch	2050 Epoch	2100 Epoch
0.034	2.35	2.63	3.22
0.068	2.46	2.74	3.33
0.085	2.50	2.78	3.37
0.169	2.61	2.89	3.48
0.423	2.75	3.03	3.62
0.507	2.78	3.06	3.65
0.845	2.86	3.14	3.73
1.69	2.97	3.25	3.84
3.38	3.09	3.36	3.96
15.20	3.36	3.62	4.21
16.90	3.37	3.64	4.23
42.25	3.55	3.80	4.40
100.00	3.73	3.96	4.56
200.00	3.87	4.08	4.67
1000.00	4.18	4.33	4.93

Table 3.5: Peak inflows (in m^3/s) for each marginal return period (including the 1 in 1 year return period used for tidally-dominant joint probability realisations) for current climate change conditions and a 9 hour event duration. Peaks are uniformly 31% higher for 2050 climate change conditions and 56% higher for 2100 climate change conditions.

Marginal Return Period (1 in *x* years)	Soroba Burn (SB_016)*	Glenshellach Burn (GL_TRIB001)	Alltan Tartach, main channel (AT_025)	Alltan Tartach, eastern tributary (AT_TRIB002)	Alltan Tartach, western tributary (AT_TRIB015)	Soroba Burn, lateral flows (SB_008i)	Soroba Burn, lateral flows (SB_005oi)	Black Lynn, lateral flows (SC_000ds)
1	3.14	2.44	2.37	0.36	0.29	0.11	0.29	0.23
2	3.46	2.70	2.61	0.40	0.32	0.12	0.31	0.25
5	4.49	3.51	3.38	0.52	0.41	0.15	0.40	0.32
10	5.23	4.08	3.94	0.60	0.48	0.17	0.46	0.36
30	6.44	5.02	4.86	0.74	0.59	0.21	0.55	0.43
50	7.03	5.49	5.30	0.81	0.65	0.22	0.59	0.47
100	7.91	6.17	5.97	0.91	0.73	0.25	0.67	0.53
200	8.89	6.94	6.72	1.02	0.82	0.28	0.74	0.59
1000	11.83	9.22	8.93	1.36	1.09	0.36	0.97	0.76

* Note: Tabulated values for Soroba Burn are pre-attenuation values; reservoir attenuation results in lower peak inflow values being applied to the model boundary.

3.3.2 Tidal-Fluvial Phasing

Within the tidally-impacted reach of the modelled system, including the Lochavullin area, worst-case flooding will occur if high fluvial flows pass at the same time as high tidal levels, with lesser flood risk occurring when tidal peaks are "out of phase" with fluvial flows. Economic appraisal should, conservatively, be based on the assumption of coincident peak timing.

For the extreme tidal signal used in modelling for this study, the tidal boundary peak occurs at 33 hours (relative to an arbitrary time datum), while inflow peaks occur at 5.75-6 hours. However, worst-case flood prediction isn't achieved simply by applying a 27 hour lag to inflows; consideration needs to be given to "travel time" between the tidal and inflow boundaries to the point of flood interest, which may vary slightly depending upon the relative strength of the tidal and fluvial flows.

As the primary location of flooding within the tidally-impacted reach is the Lochavullin area, worst-case phasing has been estimated (to the nearest 0.5 hour increment) based on maximum predicted peak water levels at model section BL_013 for each individual event. Table 3.6 summarises the lag time applied to inflows to give a maximum predicted peak at BL_013, noting that the critical lag consistently reduces as the magnitude of inflows increases (either at larger return periods or with climate change uplift).

Table 3.6: Critical lag (in hours) applied to inflows to ensure worst-case peak water levels in the Lochavullin area

Event	Current Epoch	2050 Epoch	2100 Epoch
Tidally-dominant, all return periods (i.e. 1 in 1yr fluvial inflows)	27	27	26.5
Fluvially-dominant 1 in 2yr	26.5	26.5	26
Fluvially-dominant 1 in 5yr	26.5	26	26
Fluvially-dominant 1 in 10yr	26.5	26	25.5
Fluvially-dominant 1 in 30yr	26	25.5	25
Fluvially-dominant 1 in 50yr	26	25.5	25
Fluvially-dominant 1 in 100yr	25.5	25	25
Fluvially-dominant 1 in 200yr	25.5	25	25
Fluvially-dominant 1 in 1000yr	25	25	25

3.4 Baseline Flood Risk

Maps of baseline fluvial-tidal flood risk are presented in Appendix B.

For current climate conditions, the Lochavullin coach and car park (and adjacent sections of Lochavullin Road, Lochavullin Drive and Lynn Road) is predicted to flood from the lowest return period event modelled (the 1 in 2 year event), due to overtopping of a low section of western bank of the adjacent Black Lynn. The western floodplain of the Glenshellach Burn is also predicted to begin to inundate from the 1 in 2 year event, with no impact upon receptors.

Progressively higher water depths, and greater volumes of bank overtopping in the Lochavullin area, results in the Argos carpark and a commercial/industrial unit on Crannog Lane also flooding from the 1 in 5 year event. The 1 in 5 year event is also predicted to be sufficiently large to cause the Miller Road culvert inlet and headwall to overtop slightly, without causing flooding to any receptors. For more extreme events, overtopping of this culvert entry causes flooding of residential properties on Miller Road and adjacent roads, with the Tesco and Lidl carparks and additional commercial/industrial units on Crannog Lane and Mill Lane also predicted to flood due to bank overtopping in the Lochavullin area from the 1 in 10 year event.

For residential properties, the minimum standard of protection against flood risk is therefore predicted to be at least 1 in 5 years (i.e. less than 1 in 10 years, with the 1 in 5 year event being the next lowest return period modelled). Backup from the Soroba Burn culvert under the railway line begins to cause inundation of a low-lying area north of Argyll College, but without impacting receptors.

For the 1 in 30 year event, predicted flooding in the Lochavullin area and from the Miller Road culvert entry becomes more extensive impacting a larger number of properties, with flooding from Miller Road impacting a significant area between Soroba Road and the eastern bank of the Black Lynn. Additionally, flooding over the eastern bank of the Soroba Burn begins to impact properties in the Millpark area; further downstream on the Soroba Burn, flooding over the eastern bank is predicted upstream of Lynn Road, but without impacting properties in the model. A tributary branch of the Alltan Tartach begins to flood into the woodland east of Mossfield Avenue, but without impacting any receptors.

Predicted flooding at all locations increases for larger return periods, with flooding over the western bank of the Alltan Tartach inundating the carpark north of Mossfield Stadium for the 1 in 50 year event, and flooding over the eastern bank of a tributary stream of the Alltan Tartach predicted to inundate the southern end of the rugby pitches off Glencruitten Drive for the 1 in 200 year event.

For the 1 in 1000 year event, flooding is predicted to be more extensive at all locations, with the topographic depression in Lon Mor overtopping and flooding towards the railway embankment. Further downstream, flooding from the Soroba Burn forms an overland flow route towards the flooded area of properties to the east of the Lynn Road Bridge. Mossfield Stadium and the carpark to the north is significantly inundated by this event, with additional pockets of flooding occurring upstream and downstream of the Glencruitten Terrace Bridge. Predicted flooding due to overtopping of the Miller Road culvert entry and eastern embankment of the Black Lynn through Lochavullin is extensive for this extreme event.

The fluvially-dominant joint probability realisation is predicted to cause more significant flooding at all locations for all return periods (up to and including the 1 in 1000 year event) for current climate conditions for the critical duration event, with exception of a small patch of flooding on Aird's Crescent predicted for the tidally-dominant 1 in 1000 year event which is not predicted to occur for the fluvially-dominant realisation.

Climate change is predicted to essentially trigger flooding by the same mechanisms discussed above at progressively lower return periods. For the 2050 epoch, the tidally-dominant realisation becomes critical in the Aird's Crescent area at the downstream end of the Black Lynn for the 1 in 200 year event or greater. For the 1 in 1000 year event, the existing attenuation storage upstream of Glengallen Road on the Soroba Burn is predicted to overtop, resulting in flooding on the road flowing westwards and then south around the hospital (without inundating the hospital) to impact properties on Glengallen Drive and surrounding roads.

For the 2100 epoch, the tidally-dominant realisation is critical at and downstream of the Market Street Bridge for the 1 in 30 year event or greater. Tidally-driven flooding causes inundation of Stevenson Street for the 1 in 50 year event. 1 in 200 year flooding is predicted to inundate Glencruitten Drive and Knipoch Place, but without impacting properties. Predicted flooding from the Soroba Burn both north and south of Glengallen Road is extensive for the 1 in 1000 year event.

The number of flooded properties for each scenario tested in the baseline model is presented in Table 3.7.

Table 3.7: Predicted number of flooded receptors for the baseline scenario for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	5yr	0	0	9	26	32	47	103	145
Non-Residential	<2yr	2	6	9	17	24	31	40	68
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	2yr	0	16	28	103	109	117	143	224
Non-Residential	<2yr	6	14	24	34	42	52	65	106
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	<2yr	9	32	103	124	142	149	189	242
Non-Residential	<2yr	13	28	40	61	85	106	109	129

Total present value direct and indirect property damages due to fluvial-tidal flooding over the 100 year economic appraisal period are estimated at **£17.9 million**, comprising:

£3.3 million direct residential property flood damage;
£11.9 million direct non-residential property flood damage;
£356k indirect damage to non-residential properties;

£851k emergency services response costs;
£715k evacuation and relocation costs due to flooding; and
£787k vehicle damage.

Predicted average annual damages (AAD) for the baseline increase from £205k/yr for current conditions (without climate change) to £704k/yr by 2050 and £1.87 million/yr by 2100. Analysis extrapolates between AAD estimates for 2050 and 2100 to give an estimated AAD in the last year of the appraisal period (Year 99; 2119) of £2.32 million/yr. The increasing trend in AAD due to climate change is illustrated in Figure 3.1, showing predicted AAD values based on both the economically critical 9 hour event as well as the (theoretical) hydrologically critical 3 hour event, for comparison, confirming that damages from the former are slightly higher for current climate conditions, with the difference increasing significantly over time.

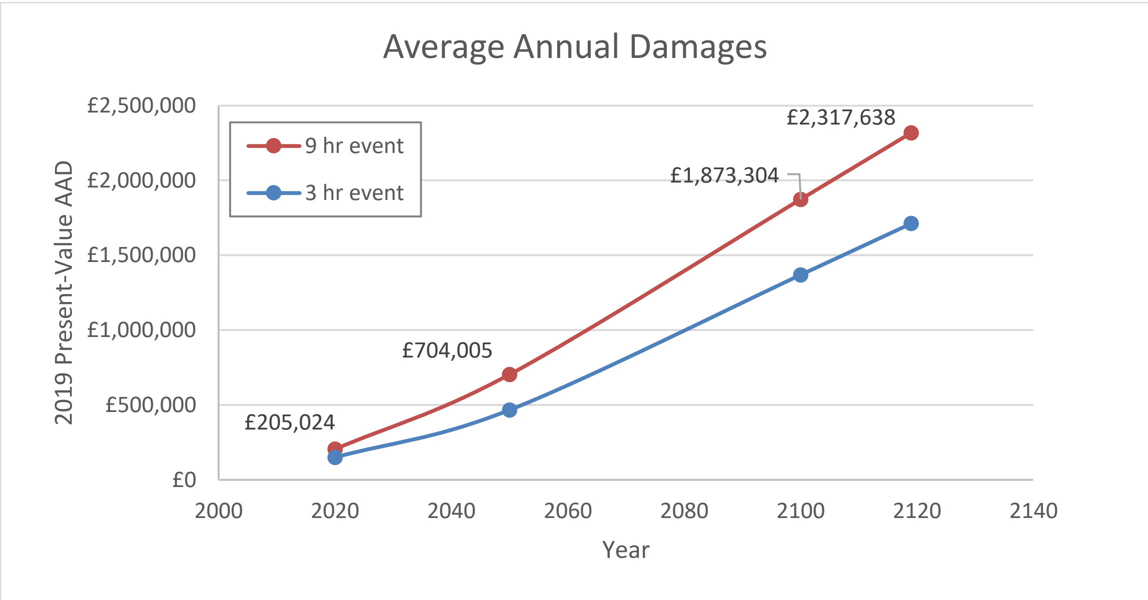

Figure 3.1: Increase in baseline average annual damages due to climate change over the economic appraisal period (i.e. Year 0 in 2020 to Year 99 in 2119). Preliminary analysis based on a 3 hour event duration is also shown for comparison.

The spatial distribution of 100 year PV damages is presented in Figure 3.2. A majority of overall damages are associated with non-residential properties in the Lochavullin area to the east of the Black Lynn.

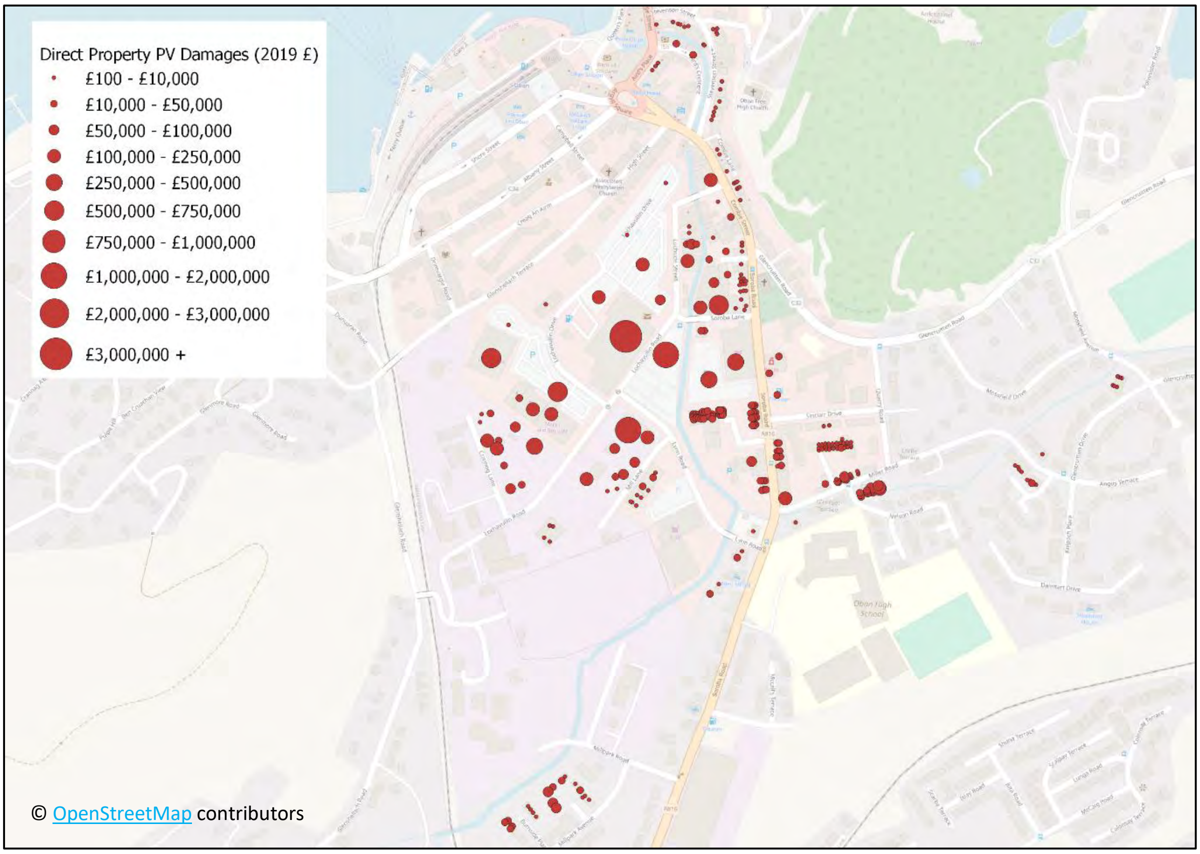

Figure 3.2: Predicted direct whole life (100 year PV) damages to properties due to fluvial-tidal flooding for baseline conditions

3.4.1 Comparison with SEPA PVA Analysis

As an outcome of 2018 National Flood Risk Assessment (NFRA), SEPA identified a number of "Potentially Vulnerable Areas" (PVAs), where flood risk is considered to be significant for current or future conditions. PVAs are used by SEPA to identify priority areas for more detailed analysis and flood risk management actions. The Oban area is within PVA 01/31, with the NFRA identifying 320 residential and 310 non-residential properties at risk from the medium likelihood (1 in 200 year return period) event from all sources of flooding (i.e. river, coastal and surface water). The estimated AAD are £1.8 million/yr, with 83% of this total (i.e. £1.5 million/yr) associated with river flooding, with greater than 95% of damages (approximately £1.48 million/yr) being associated with property and vehicle damage and the remainder associated with traffic delay/diversion costs and detrimental impact upon agricultural land. Of the approximate £1.48 million/yr AAD value, approximately 80% of these damages (£1.2 million/yr) are associated with non-residential properties, with remainder (£280k/yr) associated with residential properties and vehicles..

The approximate £1.48 million/yr AAD associated with fluvial damage to properties and vehicles from SEPA's PVA analysis is significantly greater than the estimated £205k/yr equivalent AAD estimate from this study for current climate conditions. Possible explanations for this discrepancy include:

Differences in analysis extents; the analysis extents used for PVA analysis extends further upstream into the headwater catchment of the Alltan Tartach, Glenshellach Burn and Soroba Burn than that used in this study, although the number of flooded non-receptors indicated in the PVA within these headwater areas is small and therefore shouldn't significantly impact total non-residential receptor counts (noting that residential receptor maps are not provided in the PVA).

Potential inclusion of non-ground floor receptors within PVA analysis, noting that the PVA analysis is based on a total property count of 2,200 residential properties and 820 non-residential properties, of which 630 flood for the 1 in 200 year event, whereas the economic appraisal conducted in this study is based on approximately 1,300 residential and 450 non-residential ground-floor properties (noting that predicted peak flood depths are less than 2 m for all receptors, such that upper floor properties can reasonably be excluded).

Potential use of full building areas within the PVA analysis, which is generally appropriate but will lead to an over-estimate of non-residential damages if there are multiple receptors within a single building footprint (noting that non-residential damages scale by floor area).

Potential exclusion of existing river defence walls in the NFRA modelling that informs PVA analysis, noting that existing defence levels within the lower reach of the Black Lynn (adjacent to Aird's Crescent and Stevenson Street) exceed 1 in 200 year peak tidal levels and predicted peak fluvial water levels, with limited overtopping for the 1 in 1000 year event, whereas PVA mapping indicates a high density of flooded non-residential properties in this area. Note also that predicted flooding extents slightly upstream, in the Lochavullin area, correspond well with SEPA's River Flood Extent Maps for medium (1 in 200 year return period) and low (1 in 1000 year return period) likelihoods, suggesting this discrepancy is not due to a gross difference in predicted peak water levels, and instead is more likely caused by differences in local representation of the river, floodplain and/or interface between the two.

Potential under-representation of attenuation due to in-line structures (culverts and bridges) in NFRA modelling, noting that such structures significantly alter flow behaviour – especially for extreme events – relative to a theoretical unattenuated scenario.

While there is a significant difference in estimated AAD values for this study compared to the PVA, it is therefore asserted that this difference is explainable by the additional receptor processing and local surveying conducted to inform modelling and economic appraisal in this study relative to the PVA analysis, with values presented here therefore having a higher degree of confidence.

3.5 Assessment of Individual Options

Conceptual design drawings for the options considered in economic appraisal are provided in *Report 3C: Conceptual Designs and Factsheets*. Cost summaries for options are presented in Appendix A.

3.5.1 Option Labelling

The option numbering scheme used to categorise option types examined as part of economic appraisal is set out in Table 3.8.

Table 3.8 Option labelling system

Option Series	Type
1	Bridge widening options
2	Attenuation storage options
3	Conventional flood defence (wall or embankment) options
4	Other options, not within any of the above categories
5	Combinations of two or more categories of options

3.5.2 Option 1A: Soroba Lane Bridge Widening

The single-lane Soroba Lane vehicle bridge is constricted relative to the adjacent river, especially due to the abutment and revetment at its western end (Figure 3.3). This option examined the potential benefit of widening the opening of the bridge by reducing the width of the western abutment and cutting back the revetment upstream of the bridge, along with mild bank reprofiling on both banks to improve hydraulic capacity, noting that alteration to the abutment may pose structural risks to the bridge under load which aren't considered as part of this assessment. A nominal capital cost for this option is estimated at **£192k**, inclusive of a 60% optimism bias. Maintenance costs are anticipated to be neutral relative to the baseline, such that the whole life cost estimate is also **£192k**.

Figure 3.3 Underside of the Soroba Lane vehicle bridge, viewed from upstream looking downstream

Table 3.9: Predicted number of flooded receptors for the Soroba Lane Bridge option for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	5yr	0 (0)	0 (0)	9 (0)	26 (0)	32 (0)	47 (0)	103 (0)	143 (-2)
Non-Residential	<2yr	2 (0)	6 (0)	9 (0)	16 (-1)	24 (0)	31 (0)	39 (-1)	66 (-2)
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	2yr	0 (0)	18 (2)	28 (0)	103 (0)	109 (0)	117 (0)	143 (0)	224 (0)
Non-Residential	<2yr	6 (0)	13 (-1)	23 (-1)	34 (0)	42 (0)	52 (0)	65 (0)	106 (0)
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	<2yr	9 (0)	32 (0)	103 (0)	124 (0)	142 (0)	149 (0)	189 (0)	242 (0)
Non-Residential	<2yr	13 (0)	28 (0)	40 (0)	61 (0)	85 (0)	105 (-1)	109 (0)	129 (0)

While economic appraisal indicates that the predicted benefit of this option exceeds its estimated cost, this option is predicted to achieve very modest flood damage reduction benefit, reducing PV damages over the 100 year economic appraisal period by approximately 2% or **£274k** but without improving the standard of protection for any properties currently at flood risk (Table 3.9). As such, and given unassessed structural risks which may complicate implementation of this option, the likelihood of inclusion of this option in the flood management strategy is considered low.

3.5.3 Option 1B: Market Street Bridge Widening

This arch bridge has an opening width (normal to the direction of flow) of 3.35 m, which is significantly below the bank-to-bank width of the Black Lynn further upstream and downstream, and therefore raises peak water levels upstream of the bridge, thus exacerbating flooding – particularly in the Lochavullin area.

This option examines the benefit of widening the bridge to achieve a 5.4 m flow width. Costing for the option is based on demolition and replacement of the bridge with a bridge of comparable width and function (i.e. two-lane with footpaths at both edges), given the risk that the existing bridge cannot be widened without compromising its structural stability under load. The option will also require the existing western riverside wall immediately upstream of the bridge (adjacent to the Kwik Fit premises) to be set back over a length of approximately 20 m to achieve a minimum bank-to-bank width of 5.4 m upstream of the bridge. The estimated capital cost of this option is **£2.2 million**, inclusive of a 60% optimism bias. Maintenance costs are anticipated to be neutral relative to the baseline, such that the whole life cost estimate is also **£2.2 million**.

Economic appraisal indicates that this option is capable of reducing PV flood damages by approximately 33% or **£6.0 million** over 100 years. While not improving the minimum standard of protection, it achieves a small reduction in the number of non-residential properties flooding for all return periods (and residential properties for moderate to large return periods) for current climate conditions, and generally reduces the number of properties flooding for a given return period for later climate change epochs. More generally, this option reduces the peak depth of flooding for any given flooding event at locations upstream of the bridge beyond both banks of the Black Lynn; the reduction is sometimes sufficient to protect a given property from that flood event, but otherwise reduces the predicted damages to the property.

A slight increase in the number of non-residential properties flooding from the 1 in 200 year event is predicted for the 2100 climate change epoch, with the impacted properties located downstream of the bridge and analysis confirming this flooding is associated with the tidally-dominant realisation. This may genuinely represent a detrimental impact caused by increased conveyance of fluvial flows down the river into this area during extreme tides, but may also be a modelling artefact caused by limitations in the modelling approach (noting, that critical tidal-fluvial lag/phasing was determined based on the Lochavullin area, and a larger lag time may apply further downstream of Market Street bridge; baseline flood risk in this location may therefore be slightly under-estimated, with this option reducing attenuation between Lochavullin and locations downstream of Market Street bridge, and therefore “correcting” the baseline under-estimate to some degree).

Table 3.10 lists the predicted changes in property numbers affected by flooding with Option 1B implemented.

Table 3.10: Predicted number of flooded receptors for the Market Street Bridge option for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	5yr	0 (0)	0 (0)	9 (0)	26 (0)	28 (-4)	46 (-1)	48 (-55)	127 (-18)
Non-Residential	<2yr	1 (-1)	2 (-4)	5 (-4)	13 (-4)	15 (-9)	23 (-8)	29 (-11)	51 (-17)
Property Type	**2050 Climate Change**								
	SoP	**2yr**	**5yr**	**10yr**	**30yr**	**50yr**	**100yr**	**200yr**	**1000yr**
Residential	2yr	0 (0)	15 (-1)	28 (0)	48 (-55)	53 (-56)	117 (0)	127 (-16)	219 (-5)
Non-Residential	<2yr	3 (-3)	9 (-5)	15 (-9)	26 (-8)	31 (-11)	36 (-16)	48 (-17)	79 (-27)
Property Type	**2100 Climate Change**								
	SoP	**2yr**	**5yr**	**10yr**	**30yr**	**50yr**	**100yr**	**200yr**	**1000yr**
Residential	<2yr	9 (0)	27 (-5)	48 (-55)	117 (-7)	134 (-8)	149 (0)	189 (0)	242 (0)
Non-Residential	<2yr	9 (-4)	22 (-6)	31 (-9)	51 (-10)	77 (-8)	99 (-7)	116 (7)	129 (0)

3.5.4 Option 2A: Lon Mor Attenuation

During significant storm events, the Glenshellach Burn spills over its western banks to inundate a grassed floodplain area between the river and Glenshellach Road. This option aims to enhance attenuation storage in this area, and therefore reduce peak flows and flood risk further downstream in the Soroba Burn and Black Lynn, by:

- Enhancing an existing low-level "bund" created with a public footpath between Glenshellach Road and Glengallen Road at the downstream (north-eastern) end of the inundation area to achieve a minimum 8 mAOD elevation, containing a spillway at 7.55 mAOD to limit maximum attenuation volume (above natural detention storage in the area) to less than 10,000 m^3 (i.e. to ensure that the storage area is not categorised as a reservoir under the Reservoirs (Scotland) Act 2011).
- Reforming the existing culvert arrangements under the footpath to:
  - Remove or cap two smaller diameter overflow culverts currently located above the main 900mm diameter culvert.
  - Replace the primary 900mm culvert with a 600mm diameter culvert (or else install a 600mm orifice plate upon the existing culvert if feasible and more cost-effective).

The estimated capital cost of this option is **£1.4 million**, inclusive of a 60% optimism bias. With allowance for estimated periodic inspection and maintenance/repair of the bund and spillway, the estimated whole life cost of the option is **£1.7 million**.

Economic appraisal indicates that this option is capable of reducing PV flood damaged by approximately 21% or **£3.8 million** over 100 years. This option does not alter the minimum standard of protection against flood risk, but does improve the standard of protection for individual properties, with 8, 15 and 45 fewer residential properties flooding from the 1 in 30, 100 and 200 year return period events, respectively, for current climate conditions. More generally, this option reduces the peak depth of flooding for any given flooding event at locations downstream of the railway embankment; the reduction is sometimes sufficient to protect a given property from that flood event, but otherwise reduces the predicted damages to the property.

At the point where the attenuation volume becomes full, the benefit of the option diminishes significantly, as any additional upstream flow is essentially passed forward with minimal attenuation. For current climate conditions, this occurs for return periods exceeding 1 in 200 years. For 2050 climate conditions, this occurs for return periods exceeding 1 in 30 years, reducing to 1 in 10 years by 2100. Once this occurs, a small degree of detriment (leading to increased flood depths of up to 2 cm downstream of Lon Mor) is predicted for the specific option design used in modelling; this is caused when the attenuation store becomes full prior to the inflow peak passing through, due to an effective increase in peak flow (i.e. head-driven flow through the primary outfall, plus flow down the spillway plus overtopping of the bund) relative to existing conditions.

While supplementary analysis confirms that there is no predicted detriment to receptors for any storm duration for return periods up to the design flood event (i.e. 1 in 200 year event) for current climate conditions, if this option is progressed it is nonetheless recommended that further optimisation to the design of the spillway (currently 5 m width at 7.55 mAOD), primary outfall (currently 600 mm diameter pipe) and/or bund crest level (currently 8 mAOD) is undertaken as part of detailed design to maximise the benefit provided by this option against future climate change.

The relative number of properties benefitting from the implementation of this option are given in Table 3.11.

Table 3.11: Predicted number of flooded receptors for the Lon Mor Attenuation option for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	5yr	0 (0)	0 (0)	9 (0)	22 (-4)	24 (-8)	38 (-9)	67 (-36)	145 (0)
Non-Residential	<2yr	1 (-1)	3 (-3)	7 (-2)	13 (-4)	16 (-8)	25 (-6)	33 (-7)	68 (0)
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	2yr	0 (0)	16 (0)	22 (-6)	44 (-59)	108 (-1)	118 (1)	143 (0)	225 (1)
Non-Residential	<2yr	4 (-2)	10 (-4)	15 (-9)	31 (-3)	39 (-3)	52 (0)	65 (0)	106 (0)
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	<2yr	9 (0)	24 (-8)	55 (-48)	124 (0)	141 (-1)	149 (0)	192 (3)	241 (-1)
Non-Residential	<2yr	10 (-3)	19 (-9)	33 (-7)	58 (-3)	85 (0)	102 (-4)	109 (0)	129 (0)

A variant of this option (Option 2B) was also examined in concept, effectively raising the spillway to 8 mAOD with further raising of the bund, to achieve total attenuation volume exceeding 25,000 m^3 (i.e. to assess whether a larger storage area, which would be classified as a reservoir under the Act, produces additional flood reduction benefit to justify the additional design and operational cost). However, this is predicted to achieve a negligible incremental benefit of £103k, which is very unlikely to be justified against the incremental cost of this option variation.

3.5.5 Option 2C: Mossfield Stadium Attenuation

The Mossfield Stadium, as well as the low-lying carpark area to its north, has been observed to flood due to large storm events historically. This option examines using this Council-owned site for flood attenuation storage, to reduce peak flows and hence flood risk further downstream in the Alltan Tartach and Black Lynn. The option entails:

- Lowering a section of the existing eastern site wall to enhance spill from the Alltan Tartach onto the site (modelled with a 13.6 mAOD crest height).
- Creating a bund/embankment around the southern and western edges of the pitch to contain floodwater (modelled with a 14 mAOD crest height).
- Adding a small-diameter piped outfall at the base of the bund in its south-western corner, to direct floodwater slowly back into the Alltan Tartach to the south.
- Cutting a spillway into the bund to direct high-level floodwaters back to the river to the south and ensure the bund crest is not overtopped along its length by very high return period flood events; this has been modelled as a 13.5 mAOD spillway, to ensure attenuation volumes within the stadium are below 10,000 m^3 and therefore that the storage area does not fall under the Reservoirs Act (noting that 1 in 200 year peak water levels in the river at the inlet spill are below 13.8 mAOD for a 13.6 mAOD inlet spill, with supplementary modelling predicting negligible additional benefit from increasing the level of the outlet spillway and bund).

The estimated capital cost of this option is **£1.1 million**, inclusive of a 60% optimism bias. With allowance for periodic inspection and maintenance/repair of the bund, spillway and inlet and outlet structures, the estimated whole life cost of the option is **£1.3 million**.

Economic appraisal indicates that this option is capable of reducing PV flood damaged by approximately 20% or **£3.6 million** over 100 years. By reducing peak flows at the Miller Road culvert entry, in particular, this option slightly improves the minimum standard of protection in relation to the residential flooding for current conditions, protecting 9 properties on Glenfoot Terrace from the 1 in 10 year event, with 14 fewer residential properties predicted to flood from the 1 in 50 and 1 in 100 year events. Modest benefits are persistent with climate change, with 9 fewer residential properties predicted to flood from the 1 in 50 year event by 2050, and 15 fewer from the 1 in 10 year event by 2100. More generally, this option reduces the peak depth of flooding for any given flooding event at locations downstream of the stadium; the reduction is sometimes sufficient to protect a given property from that flood event, but otherwise reduces the predicted damages to the property.

Minor detriment is predicted for the exceedance (1 in 1000 year return period) event for future climate change epochs, as the bund is predicted to overtop and spill onto Mossfield Avenue and Mossfield Drive and flood a small number of properties. If this option is progressed, detailed design for this option should therefore examine optimisation to the design of the spillway and height of the bund to mitigate this minor detriment. Alternatively, given that this detriment is only predicted to occur for an extremely rare event with climate change uplift, it may be that revision to the design of the bund and spillway can be deferred until such time as the risk of overtopping is deemed to require it.

Table 3.12 quantifies the benefit of this option in terms of relative numbers of properties inundated.

Table 3.12: Predicted number of flooded receptors for the Mossfield Stadium Attenuation option for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	**2yr**	**5yr**	**10yr**	**30yr**	**50yr**	**100yr**	**200yr**	**1000yr**
Residential	10yr	0 (0)	0 (0)	0 (-9)	13 (-13)	18 (-14)	33 (-14)	92 (-11)	143 (-2)
Non-Residential	<2yr	2 (0)	5 (-1)	7 (-2)	14 (-3)	18 (-6)	27 (-4)	33 (-7)	66 (-2)
Property Type	**2050 Climate Change**								
	SoP	**2yr**	**5yr**	**10yr**	**30yr**	**50yr**	**100yr**	**200yr**	**1000yr**
Residential	2yr	0 (0)	3 (-13)	15 (-13)	45 (-58)	100 (-9)	114 (-3)	142 (-1)	225 (1)
Non-Residential	<2yr	6 (0)	13 (-1)	18 (-6)	31 (-3)	40 (-2)	52 (0)	64 (-1)	104 (-2)
Property Type	**2100 Climate Change**								
	SoP	**2yr**	**5yr**	**10yr**	**30yr**	**50yr**	**100yr**	**200yr**	**1000yr**
Residential	2yr	0 (-9)	18 (-14)	88 (-15)	115 (-9)	139 (-3)	149 (0)	189 (0)	250 (8)
Non-Residential	<2yr	13 (0)	23 (-5)	32 (-8)	59 (-2)	85 (0)	105 (-1)	109 (0)	129 (0)

3.5.6 Option 2D: Rugby Pitches Attenuation

The rugby pitches to the south-east of Mossfield Stadium may also be a suitable location for attenuation storage to reduce risk to properties further downstream. This option could be implemented as an alternative to the Mossfield Stadium option or else to provide supplementary flood storage if both options are progressed. However, compared to the stadium, the rugby pitches are located on higher ground (average of 13.5 mAOD compared to 13.0 mAOD), with a steep hydraulic gradient in peak river levels between spill entry points (e.g. 1 in 5 year peak water level of 12.87 mAOD compared to 13.67 mAOD). To enable usage for flood attenuation would require either:

significant earthworks, to lower the level of the pitches by between at least 0.5 m and as much as 1.5 m over the majority of their area to achieve levels on the pitch at or below 13 mAOD; or,
installation of an in-line throttle into the adjacent reach of the Alltan Tartach, to induce higher water levels in the river.

The latter option is considered to be more economically viable, and has therefore been appraised. The modelled option entails:

Installing an in-line orifice along the bed of the Alltan Tartach at the north-western corner of the rugby pitches, modelled as a 1 m wide and 0.7 m high rectangular orifice, with a “failsafe” compound weir crest (14.5 mAOD crest with 1 m wide slot at 13.5 mAOD) to ensure that typical flows will remain in channel if the orifice is impacted by blockage.
Creating a lowered inflow spillway between the river and pitches upstream of the orifice, with a broad crest level of 13.8 mAOD.
Raising a bund along the western and southern perimeter of the pitches to 14.3 mAOD, tying into existing higher ground in the south-east corner of the pitches.
Creating an outflow spillway back into the Alltan Tartach (or tributary stream along the western edge of the pitches) with broad crest level of 14.0 mAOD, which thereby limits peak attenuation storage upon the pitches to less than 10,000 m^3 and thereby ensures this storage area doesn’t fall under the Reservoirs Act.
Installing a small-diameter piped outfall (with non-return valve) at the low point of the pitches (towards their south-western corner) back into the tributary stream further west, to provide additional drain-down of the pitches following a flood event.
Partially blocking the opening of the existing single-lane access bridge onto the rugby pitches from Glencruitten Drive, to effectively lower the soffit level of the bridge underside from its current value of 12.68 mAOD to 12.3 mAOD, to throttle peak flows from this tributary.

The estimated capital cost of this option is **£1.2 million**, inclusive of a 60% optimism bias. With allowance for periodic inspection and maintenance/repair of the bund, spillway, outfall and in-line structure (including periodic and responsive clearance of any blockage), the estimated whole life cost of the option is **£1.4 million**.

Economic appraisal indicates that this option is capable of reducing PV flood damaged by approximately 22% or **£3.9 million** over 100 years. The in-line throttle results in increased flooding of the rugby pitches, as intended, but also results in increased flooding of Mossfield Stadium. As such, it is not anticipated that the flood reduction benefit of these two options would be additive if both were progressed.

By reducing peak flows at the Miller Road culvert entry, in particular, this option improves the minimum standard of protection in relation to the residential flooding for current and future climate change conditions. All 9 residential properties currently predicted to flood from the 1 in 10 year event are no longer flooded by that event, with 22 fewer residential properties flooding from the 1 in 30 year event. Modest benefits are persistent with climate change, with 58 fewer residential properties predicted to flood from the 1 in 30 year event by 2050. However, detriment is predicted at higher return periods with climate change; this detriment is limited to a small number of additional properties flooding due to the 1 in 1000 year event by 2050, but with more substantial increases in the number of residential receptors for events of 1 in 100 year return period and above by 2100.

This detriment is caused by detention storage in Mossfield Stadium being exceeded, with additional flooding into the stadium essentially short-circuiting the normal flowpath and discharging back into the Alltan Tartach downstream of the in-line throttle, causing an increase in flow peaks downstream relative to baseline conditions. This detriment persists even when this option is combined with the Mossfield Stadium Attenuation option (see Section 3.6.1), suggesting that it would be difficult to make this option resilient to climate change except through significant modification.

This option has a weaker business case than the Mossfield Stadium option, which similarly aims to attenuate and store floodwater from the Alltan Tartach. It is also considered less favourably for the following reasons:

Proposed throttling within the river channel poses morphological risks, possibly increasing the rate of sediment deposition upstream of the throttle point, reducing sediment replenishment downstream of the throttle point, with the potential that these changes may alter channel shape and path over time, and induce erosion risk to adjacent roads and properties.

A significant portion of the predicted benefit of this option is associated with the consequential increase in floodwater storage at Mossfield Stadium (and the carpark area to its north), such that this option is not "independent" of the Mossfield Stadium option.

Compared to the Mossfield Stadium option, predicted climate change resilience is poorer.

Of the two candidate options entailing attenuation of Alltan Tartach flows, the Mossfield Stadium option is therefore considered the most preferable.

Table 3.13 quantifies the effect of the rugby pitch storage option in terms of property numbers at risk of flooding before and after implementation.

Table 3.13: Predicted number of flooded receptors for the Rugby Pitches Attenuation option for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	10yr	0 (0)	0 (0)	0 (-9)	4 (-22)	15 (-17)	30 (-17)	100 (-3)	143 (-2)
Non-Residential	<2yr	2 (0)	5 (-1)	7 (-2)	14 (-3)	18 (-6)	27 (-4)	33 (-7)	65 (-3)
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	5yr	0 (0)	0 (-16)	13 (-15)	45 (-58)	102 (-7)	116 (-1)	143 (0)	227 (3)
Non-Residential	<2yr	6 (0)	13 (-1)	18 (-6)	32 (-2)	41 (-1)	52 (0)	64 (-1)	110 (4)
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	2yr	0 (-9)	14 (-18)	88 (-15)	119 (-5)	137 (-5)	167 (18)	191 (2)	295 (53)
Non-Residential	<2yr	13 (0)	23 (-5)	32 (-8)	58 (-3)	85 (0)	101 (-5)	109 (0)	130 (1)

Note: Cells highlighted in pink denote potential detrimental effect.

3.5.7 Option 3A: Black Lynn Flood Defences

Flood risk in the Lochavullin area is primarily caused by river banks in this area being low relative to peak water levels in the river, with the western bank of the Black Lynn being as low as 3.2 mAOD adjacent to the coach and carpark, which is below the predicted 1 in 2 year peak water level at this location (3.34 mAOD), and significantly below higher return period peak water levels (e.g. 3.72 mAOD for the 1 in 10 year event, increasing to 4.26 mAOD for the 1 in 200 year event). While other options may help to reduce peak water levels in this area (and the adjacent area beyond the eastern bank of the river), an engineered flood defence may be the most cost-effective measure of significantly improving flood protection in this area – provided it can be demonstrated to not detrimentally increase flood risk elsewhere.

Noting that the Lochavullin area currently floods at relatively low river levels, option appraisal first examined raising defences to a minimum elevation of 3.8 mAOD, which is between the 1 in 10 year and 1 in 30 year predicted peak local water levels, using either walls or embankments as appropriate. This requires approximately 100 m of bank raising along each bank of the river (i.e. approximately 209 m of bank raising in total). The estimated capital cost of this option is **£1.1 million**, inclusive of a 60% optimism bias, based on raising a flood wall along the eastern bank in the Lochavullin area and raising the existing embankment along the western bank (with costs inclusive of piling of the western embankment, to minimise flooding via subsurface pathways). With allowance for periodic inspection and maintenance/repair of the embankment and flood wall, the estimated whole life cost of the option is **£1.2 million**.

Economic appraisal indicates that this option is capable of reducing PV flood damaged by approximately 19% or **£3.3 million** over 100 years. This option achieves the majority of its benefit by protecting non-residential properties in the Lochavullin area from flooding in response to low return period events, and otherwise by reducing the overall volume of overtopping from a given larger return period event and therefore reducing peak flooding depths and hence damages.

The option is predicted to achieve benefit for current climate conditions for all return periods for the critical duration event. However, for non-critical event durations (as well as for future climate change scenarios), model analysis indicates an increase in the number of receptors in the area beyond the eastern bank of the Black Lynn, as this option effectively “cuts off” a return pathway for floodwaters (originating from overtopping of the Black Lynn further upstream as well as overtopping of the Miller Road culvert entry). As such, while this option is predicted to achieve substantial overall economic benefit, it cannot be progressed in isolation and must instead be progressed as part of an option combination which mitigates predicted detriment. Note that this same caveat would apply to options involving raising Black Lynn defences further above 3.8 mAOD, with the likelihood that the predicted detriment elsewhere becomes progressively worse; it is for this reason that higher defence levels have not been considered in isolation.

Table 3.14 quantifies the benefit of this option in terms of relative numbers of properties inundated.

Table 3.14: Predicted number of flooded receptors for the Black Lynn Defence (3.8 mAOD) option for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	5yr	0 (0)	0 (0)	9 (0)	26 (0)	32 (0)	47 (0)	103 (0)	142 (-3)
Non-Residential	5yr	0 (-2)	0 (-6)	1 (-8)	14 (-3)	19 (-5)	29 (-2)	34 (-6)	65 (-3)
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	2yr	0 (0)	18 (2)	28 (0)	60 (-43)	108 (-1)	117 (0)	142 (-1)	224 (0)
Non-Residential	2yr	0 (-6)	6 (-8)	17 (-7)	33 (-1)	41 (-1)	52 (0)	64 (-1)	106 (0)
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	<2yr	9 (0)	31 (-1)	103 (0)	125 (1)	135 (-7)	149 (0)	189 (0)	242 (0)
Non-Residential	<2yr	4 (-9)	24 (-4)	34 (-6)	57 (-4)	85 (0)	101 (-5)	112 (3)	129 (0)

Note: Cells highlighted in pink denote potential detrimental effect.

Note that a variant of this option, based on a higher minimum defence level of 4.0 mAOD (between the 1 in 30 year and 1 in 50 year river level), is also considered as part of incremental refinement of option combinations; this variant is labelled Option 3B. Higher defence levels (of up to 4.3 mAOD; above the 1 in 200 year river level) are also considered as part of potential long-term measures (see Section 3.9).

3.5.8 Option 3C: Millpark Corridor Flood Defences

Residential properties in the Millpark area, on the east bank of the Soroba Burn downstream of the railway embankment, are predicted to begin to flood for the 1 in 50 year or greater events for current conditions, reducing to the 1 in 10 year event by 2100. This local option aims to protect these properties from flood risk by constructing a conventional engineered flood defence embankment along the eastern bank of the river, extending south-eastwards tying into existing higher ground at its southern end, and adjoining a raised inlet headwall for the Millpark Road culvert at its northern end.

The capital cost of this option is estimated at **£296k**, inclusive of a 60% optimism bias. With allowance for periodic inspection and repair/maintenance of the embankment and headwall, the estimated whole life cost of the option is **£340k**. Economic appraisal indicates that this option achieves a relatively minor flood damage reduction benefit of **£295k**. While it does improve the standard of protection for local residential properties, the existing standard of protection for properties in this area is already reasonable (between 1 in 10 year and 1 in 200 year SoP), and this benefit is offset by increased damage further downstream in the Lochavullin area, with the standard of protection reduced for 3 non-residential properties and 2 residential properties for current conditions and up to 6 properties by 2050. Therefore, this option is not viable by itself and is unlikely to be viable as part of an option combination.

The relative effect of the Millpark defences on property flooding is quantified in Table 3.15.

Table 3.15: Predicted number of flooded receptors for the Millpark Corridor Defence (6.4 mAOD) option for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	5yr	0 (0)	0 (0)	9 (0)	22 (-4)	27 (-5)	49 (2)	97 (-6)	141 (-4)
Non-Residential	<2yr	2 (0)	6 (0)	9 (0)	18 (1)	24 (0)	33 (2)	40 (0)	66 (-2)
Property Type	**2050 Climate Change**								
	SoP	**2yr**	**5yr**	**10yr**	**30yr**	**50yr**	**100yr**	**200yr**	**1000yr**
Residential	2yr	0 (0)	18 (2)	22 (-6)	93 (-10)	106 (-3)	117 (0)	141 (-2)	220 (-4)
Non-Residential	<2yr	6 (0)	14 (0)	24 (0)	38 (4)	42 (0)	52 (0)	65 (0)	106 (0)
Property Type	**2100 Climate Change**								
	SoP	**2yr**	**5yr**	**10yr**	**30yr**	**50yr**	**100yr**	**200yr**	**1000yr**
Residential	<2yr	9 (0)	27 (-5)	93 (-10)	125 (1)	142 (0)	147 (-2)	188 (-1)	240 (-2)
Non-Residential	<2yr	13 (0)	30 (2)	40 (0)	61 (0)	85 (0)	105 (-1)	111 (2)	129 (0)

Note: Cells highlighted in pink denote potential detrimental effect.

3.5.9 Option 4A: Miller Road Culvert Dualling

Flooding due to surcharge and headwall overtopping at the Miller Road culvert entry on the Alltan Tartach is an important flooding mechanism, predicted to occur for events of 1 in 5 year return period or greater, causing property flooding for events of 1 in 10 year return period or greater. Once water overtops the headwall, there is very limited capacity in local topographic depressions before this floodwater begins to "flow downhill" along Miller Road, Soroba Road and adjoining minor roads to inundate a significant area between Miller Road and Soroba Lane within the eastern floodplain of the Black Lynn.

Increasing the capacity for culvert flow, by creating a new dualled culvert line, would obviously reduce the risk of flooding by this mechanism. Implementation of such an option is dependent upon existing constraints along the potential route. A nominal cost for the option, based on creation of a new dualled rectangular culvert line over an approximately 200 m length, is **£1.3 million**, inclusive of a 60% optimism bias but with no specific allowance for diversion of either the new culvert or of existing utilities in the event of clashes, as utility information along the route, other than Scottish Water drainage network, is unknown. With allowance for periodic inspection (including CCTV or man-entry surveying of the culvert, as well as visual inspection of the outlet, inlet and headwall) and maintenance/repair (possibly including jetting of debris, as well as periodic and responsive clearance of the inlet trash screen following large flow events), the estimated whole life cost of the option is **£1.4 million**.

Increasing overall conveyance between the Alltan Tartach and upper reach of the Black Lynn will obviously increase existing flood risk in the Lochavullin area. As such, this option has not been assessed in isolation, as it will not be viable in isolation; instead, it is considered as an "add-on" option to the preferred combination of other options which themselves reduce flooding in the Lochavullin area, to ensure that downstream detriment is mitigated (see Section 3.6).

3.5.10 Option 4B: Miller Road Floodwater Routing

As an alternative to increasing the flow capacity of the Miller Road culvert, a routing option was examined to attempt to contain and route floodwater back towards the Black Lynn through modification to local roads, and the addition of "speedbump" road raising to maximise local storage upon the road surface.

The capital cost of this option has been provisionally estimated as **£1.1 million**, inclusive of a 60% optimism bias. With allowance for periodic inspection and maintenance/repair, the estimated whole life cost of the option is **£1.3 million**. Economic appraisal indicates that this option achieves a flood damage reduction benefit of **£13k**, such that this option is not cost-beneficial, even ignoring maintenance costs over the appraisal period.

While it slightly improves the standard of protection for a small number of residential properties in the area between Miller Road and Soroba Lane, thereby reducing local flood damages, this is offset by slightly higher flood damages in the Lochavullin area. The option would also be disruptive to implement, have a relatively high failure risk (if any one part of the "bunded" perimeter is damaged) and has the impact of increasing the depths of roadway flooding along Miller Road and at the Miller Road – Soroba Road intersection, which is likely to be concerning to local residents and commuters. Given these considerations, this option is not economically viable by itself and, even if more effective in combination with other options, is unlikely to be a preferred flood management measure.

The relative impact of this option on flooded property numbers is shown in Table 3.16.

Table 3.16: Predicted number of flooded receptors for the Miller Road Floodwater Routing option for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	5yr	0 (0)	0 (0)	6 (-3)	21 (-5)	33 (1)	51 (4)	107 (4)	146 (1)
Non-Residential	<2yr	2 (0)	6 (0)	9 (0)	18 (1)	25 (1)	31 (0)	40 (0)	68 (0)
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	2yr	0 (0)	11 (-5)	23 (-5)	107 (4)	116 (7)	122 (5)	141 (-2)	227 (3)
Non-Residential	<2yr	6 (0)	13 (-1)	25 (1)	34 (0)	42 (0)	52 (0)	65 (0)	110 (4)
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	<2yr	6 (-3)	33 (1)	107 (4)	130 (6)	143 (1)	149 (0)	189 (0)	268 (26)
Non-Residential	<2yr	13 (0)	29 (1)	40 (0)	61 (0)	85 (0)	106 (0)	116 (7)	130 (1)

Note: Cells highlighted in pink denote potential detrimental effect.

3.5.11 Summary of Individual Option Economic Performance

Table 3.17 summarises the economic appraisal outcomes in relation to each of the individual options considered. The following options are recommended for consideration, either by themselves or in combination with other options:

Option 1B: Market Street Bridge Widening
Option 2A: Lon Mor Attenuation (<10,000 m^3)
Option 2C: Mossfield Stadium Attenuation
Option 3A/B: Black Lynn Flood Defence Walls (only in combination with other options)
Option 4A: Miller Road Culvert Dualling (only in combination with other options)

The following options are demonstrated to achieve an economic business case (i.e. BCR>1), but are less preferred:

Option 1A: Soroba Lane Bridge Widening – limited benefit, and potential structural risks to bridge
Option 2C: Lon Mor Attenuation (25,000 m^3) – no incremental business case compared to the lower storage version, and would fall under the Reservoirs Act.
Option 2D: Rugby Pitches Attenuation – potential morphological risks, poor climate change resilience, and reliant upon increasing flood storage within Mossfield Stadium (therefore, unlikely to combine well with this option), with weaker business case than Mossfield Stadium option.

The following options are predicted to lack cost-effectiveness for managing flood risk:

Option 3C: Millpark Corridor Flood Defences – the existing standard of protection for local properties is reasonable, such that the economic benefit achieved by increasing their standard of protection is limited, and this option is also predicted to pass flood risk downstream. However, this option may become more economically viable in the future, due to climate change.
Option 4B: Miller Road Floodwater Routing – achieves very little local benefit for small return period events and predicted to exacerbate flooding locally and downstream from moderate to large return period events.

Option 4A (Miller Road Culvert Dualling) may be suitable as part of an option combination that addresses the downstream flood risk detriment it would cause in isolation; the economic performance of this option will only be assessed incrementally as part of such an option combination.

Table 3.17: Summary of economic appraisal of individual options. All costs are inclusive of a 60% optimism bias/risk contingency.

Option Label	Description	Minimum Standard of Protection to Properties			Cost & Benefit Values				Benefit-Cost Ratio	Likelihood of inclusion in preferred option	Comment
		Current Climate	2050 Climate	2100 Climate	Capital Cost (incl. 60% Optimism Bias)	Average Annual Operational Cost (incl. 60% Optimism Bias)	PV Whole Life Cost (incl. 60% Optimism Bias)	PV Whole Life Benefit			
1A	Soroba Lane bridge widening	5yr (residential) / <2yr(non-res)	2yr (residential) / <2yr (non-res)	<2yr	£192,000	£0	£192,000	£273,769	**1.43**	Low	Cost-effective, but economic benefit is small, and implementation may pose risk to structural integrity of bridge
1B	Market Street Bridge widening	5yr (residential) / <2yr(non-res)	2yr (residential) / <2yr (non-res)	<2yr	£2,159,385	£0	£2,159,385	£5,952,714	**2.76**	High	Effective option, but may be technically challenging
2A	Lon Mor attenuation (10,000 m^3 storage)	5yr (residential) / <2yr(non-res)	2yr (residential) / <2yr (non-res)	<2yr	£1,438,092	£7,190	£1,652,458	£3,769,976	**2.28**	High	Cost-effective; requires some optimisation to improve resilience to climate change
2B	Lon Mor attenuation: (25,000 m^3 storage)	5yr (residential) / <2yr(non-res)	2yr (residential) / <2yr (non-res)	<2yr	£1,465,801	£7,329	£1,684,297	£4,126,400	**2.45**	None	Increased storage relative to 2a provides small benefit, and therefore marginal incremental business case (IBCR=0.92) => 2a preferred variant
2C	Mossfield Stadium Attenuation	10yr (residential) / <2yr(non-res)	2yr (residential) / <2yr (non-res)	2yr (residential) / <2yr (non-res)	£1,120,589	£5,603	£1,287,627	£3,645,116	**2.83**	High	Cost-effective
2D	Rugby pitches attenuation	10yr (residential) / <2yr(non-res)	5yr (residential) / <2yr (non-res)	2yr (residential) / <2yr (non-res)	£1,245,193	£6,226	£1,430,805	£3,866,622	**2.70**	Low	Cost-effective, but risky (entails in-channel throttling, increasing upstream water levels) and predicted to have poor resilience to climate change.
3A	Black Lynn flood defence walls (3.8 mAOD)	5yr	2yr	<2yr	£1,139,639	£2,849	£1,224,577	£3,345,975	**2.73**	High	Cost-effective, but causes a detriment to some properties in response to shorter duration events; cannot be progressed unless this detriment is addressed.
3C	Millpark Corridor flood defences	5yr (residential) / <2yr(non-res)	2yr (residential) / <2yr (non-res)	<2yr	£296,018	£1,480	£340,144	£294,729	**0.87**	Low	No business case for this option, and causes detriment downstream.
4A	Miller Road Culvert Dualling	N/A	N/A	N/A	£1,330,429	£3,326	£1,429,588	N/A	**N/A**	TBC	Not examined as an individual option, due to certainty it will cause downstream detriment; must be combined with other option that either attenuates upstream flows and/or reduces downstream flooding.
4B	Miller Rd floodwater routing	5yr (residential) / <2yr(non-res)	2yr (residential) / <2yr (non-res)	<2yr	£1,144,168	£5,721	£1,314,721	£12,595	**0.01**	None	No business case for this option (in isolation or in combination), and technically challenging to implement

3.6 Assessment of Option Combinations

Where multiple options are combined, it is important to determine that there is an incremental business case for investment, as well as establishing that the overall benefit of the option exceeds the overall cost. For a combination of any two options, the incremental business case is conducted by first establishing which individual option has the highest BCR (termed the “leading option”), and then comparing the additional whole life benefit of the option combination compared to the leading option alone against the additional whole life cost of the option combination compared to the leading option alone. Where incremental benefits exceed incremental costs (i.e. where the incremental cost-benefit ratio, IBCR, exceeds 1), this option combination becomes the leading option. Otherwise, the combination is discarded from further consideration (although some options may have benefits which are “more additive” with some options than others, such that it can sometimes be worthwhile to consider a given option as part of other option combinations even when it is demonstrated to not have an incremental business as part any given option combination). The BCR and IBCR are therefore both important for assessing the economic performance of an option combination.

3.6.1 Option 2E (Lon Mor & Mossfield Stadium Attenuation)

The Lon Mor option attenuates flows within the Soroba Burn, while the Mossfield Stadium option attenuates flows in the Alltan Tartach (and is economically favourable to the Rugby Pitches option that has a similar effect). However, both options attenuate flows below the confluence point of these two watercourses, in the Black Lynn. As such, the flood damage reduction benefit of combining these options would not necessarily be additive. While the overall BCR of this option (**2.08**) is less than that for each individual option, it is nonetheless demonstrated to be a cost-effective combination, with an IBCR for the Mossfield Stadium option (relative to progressing the Lon Mor attenuation option by itself) of **1.82**.

The relative effect of this combination on the predicted number of properties flooding is quantified in Table 3.18.

Table 3.18: Predicted number of flooded receptors for Option 2e for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	10yr	0 (0)	0 (0)	0 (-9)	9 (-17)	12 (-20)	21 (-26)	37 (-66)	143 (-2)
Non-Residential	<2yr	1 (-1)	3 (-3)	6 (-3)	10 (-7)	13 (-11)	18 (-13)	30 (-10)	66 (-2)
Property Type	**2050 Climate Change**								
	SoP	**2yr**	**5yr**	**10yr**	**30yr**	**50yr**	**100yr**	**200yr**	**1000yr**
Residential	2yr	0 (0)	3 (-13)	9 (-19)	29 (-74)	100 (-9)	116 (-1)	142 (-1)	225 (1)
Non-Residential	<2yr	3 (-3)	7 (-7)	13 (-11)	24 (-10)	33 (-9)	51 (-1)	65 (0)	106 (0)
Property Type	**2100 Climate Change**								
	SoP	**2yr**	**5yr**	**10yr**	**30yr**	**50yr**	**100yr**	**200yr**	**1000yr**
Residential	2yr	0 (-9)	12 (-20)	28 (-75)	113 (-11)	141 (-1)	149 (0)	192 (3)	249 (7)
Non-Residential	<2yr	9 (-4)	14 (-14)	29 (-11)	56 (-5)	85 (0)	102 (-4)	109 (0)	129 (0)

Note: Cells highlighted in pink denote potential detrimental effect.

3.6.2 Option 2F (Rugby Pitches & Mossfield Stadium Attenuation)

Both the Rugby Pitches and Mossfield Stadium attenuation options result in increased floodwater storage within Mossfield Stadium and the carpark area to its north. As such, it is expected that the flood damage reduction benefit of combining these two options is much less than additive. The incremental BCR for the Rugby Pitches option (relative to progressing the Mossfield Stadium option by itself) is **0.92**, indicating that this option combination is marginally economically inefficient, even though overall benefits exceed overall costs.

The relative effect of this combination on the predicted number of properties flooding is quantified in Table 3.19.

Table 3.19: Predicted number of flooded receptors for Option 2f for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	10yr	0 (0)	0 (0)	0 (-9)	4 (-22)	6 (-26)	20 (-27)	88 (-15)	141 (-4)
Non-Residential	<2yr	2 (0)	5 (-1)	7 (-2)	13 (-4)	15 (-9)	23 (-8)	32 (-8)	64 (-4)
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	5yr	0 (0)	0 (-16)	6 (-22)	33 (-70)	96 (-13)	107 (-10)	135 (-8)	230 (6)
Non-Residential	<2yr	6 (0)	13 (-1)	15 (-9)	29 (-5)	38 (-4)	50 (-2)	63 (-2)	109 (3)
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	2yr	0 (-9)	5 (-27)	84 (-19)	113 (-11)	133 (-9)	150 (1)	194 (5)	286 (44)
Non-Residential	<2yr	13 (0)	21 (-7)	31 (-9)	56 (-5)	84 (-1)	101 (-5)	110 (1)	130 (1)

Note: Cells highlighted in pink denote potential detrimental effect.

3.6.3 Option 2G (Lon Mor, Rugby Pitches & Mossfield Stadium Attenuation)

While the business case for combining the Lon Mor and Mossfield Stadium options (i.e. Option 2E) is predicted to be strong, the incremental benefit of also implementing the Rugby Pitches option is limited (approximately £718k) and much less than the incremental whole life cost (£1.4 million). As such, the incremental BCR for the Rugby Pitches option (relative to Option 2E) is **0.50**; along with similar outcomes for Option 2F, this gives further indication that there is no business case for combining the Rugby Pitches option with the Mossfield Stadium option. Option 2E is therefore the most viable combination of "attenuation-only" option elements.

The relative effect of this combination on the predicted number of properties flooding is quantified in Table 3.20.

Table 3.20: Predicted number of flooded receptors for Option 2g for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	50yr	0 (0)	0 (0)	0 (-9)	0 (-26)	0 (-32)	14 (-33)	33 (-70)	141 (-4)
Non-Residential	<2yr	1 (-1)	3 (-3)	5 (-4)	8 (-9)	13 (-11)	18 (-13)	30 (-10)	65 (-3)
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	10yr	0 (0)	0 (-16)	0 (-28)	30 (-73)	92 (-17)	108 (-9)	135 (-8)	230 (6)
Non-Residential	<2yr	3 (-3)	7 (-7)	10 (-14)	24 (-10)	33 (-9)	50 (-2)	64 (-1)	109 (3)
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	5yr	0 (-9)	0 (-32)	22 (-81)	113 (-11)	135 (-7)	150 (1)	198 (9)	286 (44)
Non-Residential	<2yr	9 (-4)	14 (-14)	28 (-12)	56 (-5)	83 (-2)	99 (-7)	109 (0)	130 (1)

Note: Cells highlighted in pink denote potential detrimental effect.

3.6.4 Option 5A (Lon Mor & Mossfield Stadium Attenuation, Market Street Bridge Widening)

The favoured attenuation option combination is Option 2E (Lon Mor plus Mossfield Stadium attenuation), which attenuates flows in all of the Alltan Tartach, Soroba Burn and Black Lynn. Option 5A examines the business case for combining this with widening of the Market Street Bridge, which has the effect of reducing peak water levels in the Lochavullin area of the Black Lynn by removing an existing bottleneck. This option combination is predicted to reduce flood damages substantially, by 54% (£9.6 million), and achieve an overall BCR of **1.88**, with an IBCR (for the attenuation element, relative to widening the bridge alone) of **1.24**.

The relative effect of this combination on the predicted number of properties flooding is quantified in Table 3.21.

Table 3.21: Predicted number of flooded receptors for Option 5a for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	10yr	0 (0)	0 (0)	0 (-9)	9 (-17)	9 (-23)	21 (-26)	34 (-69)	127 (-18)
Non-Residential	2yr	0 (-2)	1 (-5)	3 (-6)	6 (-11)	9 (-15)	13 (-18)	22 (-18)	52 (-16)
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	2yr	0 (0)	3 (-13)	9 (-19)	28 (-75)	45 (-64)	114 (-3)	126 (-17)	220 (-4)
Non-Residential	<2yr	1 (-5)	5 (-9)	7 (-17)	15 (-19)	24 (-18)	36 (-16)	48 (-17)	79 (-27)
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	2yr	0 (-9)	9 (-23)	27 (-76)	107 (-17)	129 (-13)	149 (0)	191 (2)	249 (7)
Non-Residential	<2yr	7 (-6)	13 (-15)	22 (-18)	50 (-11)	77 (-8)	98 (-8)	111 (2)	129 (0)

Note: Cells highlighted in pink denote potential detrimental effect.

3.6.5 Option 5B (Lon Mor & Mossfield Stadium Attenuation, Market Street Bridge Widening, Black Lynn Flood Defences to 3.8mAOD)

Combining Option 5A with Black Lynn flood defences (to a 3.8 mAOD minimum crest level) achieves £11.6 million whole life benefits at a capital cost of £5.9 million and whole life cost of £6.3 million, therefore achieving a BCR of **1.83**. The IBCR for inclusion of flood defences is **1.64**.

The relative effect of this combination on the predicted number of properties flooding is quantified in Table 3.22.

Table 3.22: Predicted number of flooded receptors for Option 5b for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	10yr	0 (0)	0 (0)	0 (-9)	9 (-17)	11 (-21)	21 (-26)	34 (-69)	127 (-18)
Non-Residential	10yr	0 (-2)	0 (-6)	0 (-9)	1 (-16)	1 (-23)	3 (-28)	15 (-25)	50 (-18)
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	2yr	0 (0)	3 (-13)	9 (-19)	28 (-75)	44 (-65)	71 (-46)	126 (-17)	220 (-4)
Non-Residential	2yr	0 (-6)	1 (-13)	1 (-23)	10 (-24)	21 (-21)	34 (-18)	46 (-19)	79 (-27)
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	2yr	0 (-9)	12 (-20)	27 (-76)	107 (-17)	129 (-13)	149 (0)	190 (1)	239 (-3)
Non-Residential	2yr	0 (-13)	3 (-25)	15 (-25)	50 (-11)	77 (-8)	98 (-8)	111 (2)	127 (-2)

Note: Cells highlighted in pink denote potential detrimental effect.

3.6.6 Option 5C (Lon Mor & Mossfield Stadium Attenuation, Market Street Bridge Widening, Black Lynn Flood Defences to 4.0mAOD)

The benefit of providing slightly higher minimum defence levels on the Black Lynn was examined in this option combination, relative to Option 5B. Achieving a minimum defence level of 4.0 mAOD instead of 3.8 mAOD requires higher defences over a longer bank length, at an estimated incremental capital cost of approximately £452k (including 60% optimism bias). However, higher defences are predicted to achieve only £203k of additional whole life flood damage reduction benefit, such that Option 5B remains the leading option combination.

The relative effect of this combination on the predicted number of properties flooding is quantified in Table 3.23.

Table 3.23: Predicted number of flooded receptors for Option 5c for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	10yr	0 (0)	0 (0)	0 (-9)	9 (-17)	12 (-20)	21 (-26)	36 (-67)	127 (-18)
Non-Residential	10yr	0 (-2)	0 (-6)	0 (-9)	1 (-16)	3 (-21)	3 (-28)	5 (-35)	45 (-23)
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	2yr	0 (0)	3 (-13)	9 (-19)	28 (-75)	44 (-65)	59 (-58)	126 (-17)	220 (-4)
Non-Residential	2yr	0 (-6)	1 (-13)	3 (-21)	3 (-31)	10 (-32)	29 (-23)	41 (-24)	77 (-29)
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	2yr	0 (-9)	12 (-20)	27 (-76)	107 (-17)	128 (-14)	149 (0)	189 (0)	239 (-3)
Non-Residential	2yr	0 (-13)	3 (-25)	5 (-35)	47 (-14)	76 (-9)	98 (-8)	111 (2)	128 (-1)

Note: Cells highlighted in pink denote potential detrimental effect.

3.6.7 Option 5D (Lon Mor & Mossfield Stadium Attenuation, Market Street Bridge Widening, Black Lynn Flood Defences to 3.8mAOD, Miller Road Culvert Dualling)

The benefit of dualling the Miller Road culvert was examined in this option combination, relative to Option 5B. Dualling this culvert will reduce flood risk associated with overtopping of this culvert inlet, with the potential consequence of increased flows and hence flooding downstream in the Black Lynn; the option combination therefore has the potential to cause detriment relative to existing (baseline) conditions unless the proposed upstream attenuation fully mitigates increased flow capacity for this culvert. Due to model stability issues, culvert dualling was not explicitly modelled; instead, this option was modelled as a widening of the existing culvert from 1.84 m to 3.3 m.

Dualling of the culvert has an estimated capital cost of £1.3 million (inclusive of 60% optimism bias) and whole life cost of £1.4 million, whereas the incremental benefit of dualling as part of this option combination is predicted to be slightly lower (£1.3 million), leading to an IBCR of **0.92**. As such, Option 5B remains the leading option combination, although it cannot be ruled out that culvert dualling may have an incremental business case as part of a different option combination, or else if the cost savings can be realised (either by changes to the design as part of detailed design, and/or a reduction in the risk contingency).

The relative effect of this combination on the predicted number of properties flooding is quantified in Table 3.24.

Table 3.24: Predicted number of flooded receptors for Option 5d for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	50yr	0 (0)	0 (0)	0 (-9)	0 (-26)	0 (-32)	2 (-45)	10 (-93)	104 (-41)
Non-Residential	50yr	0 (-2)	0 (-6)	0 (-9)	0 (-17)	0 (-24)	2 (-29)	13 (-27)	47 (-21)
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	10yr	0 (0)	0 (-16)	0 (-28)	6 (-97)	10 (-99)	28 (-89)	103 (-40)	189 (-35)
Non-Residential	10yr	0 (-6)	0 (-14)	0 (-24)	7 (-27)	16 (-26)	31 (-21)	43 (-22)	78 (-28)
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	5yr	0 (-9)	0 (-32)	5 (-98)	77 (-47)	106 (-36)	138 (-11)	152 (-37)	264 (22)
Non-Residential	2yr	0 (-13)	3 (-25)	15 (-25)	48 (-13)	75 (-10)	97 (-9)	111 (2)	130 (1)

Note: Cells highlighted in pink denote potential detrimental effect.

3.6.8 Option 5E (Lon Mor & Mossfield Stadium Attenuation, Market Street Bridge Widening, Black Lynn Flood Defences to 4.0mAOD, Miller Road Culvert Dualling)

While a higher Black Lynn defence level and dualling of the Miller Road culvert have each been demonstrated to lack a business case, the increased flow into the Black Lynn caused by culvert dualling may be offset by increased defence levels in the Black Lynn, such that these elements were considered incrementally as a combination, relative to Option 5B.

These options are shown, in combination, to be capable of reducing fluvial flooding damages over the next 100 years by up to 77% or £13.8 million at a whole life cost of £8.2 million (with capital cost element of £7.6 million), achieving an overall BCR of **1.68**. This option combination is predicted to increase the minimum standard of flood protection for residential properties from 1 in 5 years (currently) to 1 in 50 years for existing climate conditions, with the minimum SoP for non-residential properties improved from less than 1 in 2 years to 1 in 200 years for existing climate conditions. The calculated IBCR (for Miller Road culvert dualling plus raising the Black Lynn flood defence level from 3.8 mAOD to 4.0 mAOD) is **1.17**, indicating a marginal incremental business case for adding these elements to Option 5B.

Costing for the Miller Road culvert dualling option is primarily based on Environment Agency (2014)[8] unit costs that are based on out-turn costs for 37 recent culvert installation schemes inclusive of "all associated works". Likewise, costing for the proposed flood defence walls and embankments is based on Environment Agency Unit Cost Database[9] costing, which is also based on out-turn costs for previous flood storage and defence schemes constructed in the UK over the last 30 years. As such, the assumed general items uplift (amounting to a 55% uplift) applied to all option costs in this analysis are likely to be conservative, as some or all general items costs will be bundled in out-turn costing and therefore may be double-counted. Likewise, out-turn costing will be inclusive of actual (averaged) risk realisation over the construction phase of the projects used by the EA to derive unit costing, rather than a risk-free estimate.

[8] Environment Agency (2014). Cost estimation for culverts – summary of evidence (Report SC080039/R4).
[9] Environment Agency (2010). Flood risk management estimating guide.

As such, there will be some double-counting of risk by using these unit costs in combination with the 60% optimism bias assumed for all options in this analysis. In both cases, the amount of uplift implicitly included in unit costing cannot be discerned based on available information, such that it is conservative but reasonable at this stage of design to retain the standard general items and optimism bias uplifts. However, it would also be reasonable to expect that costs are more likely to reduce than increase through detailed design and construction, and therefore the business case for progressing Option 5E to improve. Given this, and that Option 5E significantly improves the minimum standard of protection achieves from 1 in 10 years (Option 5B) to 1 in 50 years for residential properties and 1 in 100 years for non-residential properties, Option 5E is considered the leading option combination for achieving flood management objectives.

The relative effect of this combination on the predicted number of properties flooding is quantified in Table 3.25.

Table 3.25: Predicted number of flooded receptors for Option 5e for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	50yr	0 (0)	0 (0)	0 (-9)	0 (-26)	0 (-32)	2 (-45)	10 (-93)	104 (-41)
Non-Residential	100yr	0 (-2)	0 (-6)	0 (-9)	0 (-17)	0 (-24)	0 (-31)	2 (-38)	43 (-25)
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	10yr	0 (0)	0 (-16)	0 (-28)	6 (-97)	10 (-99)	25 (-92)	103 (-40)	189 (-35)
Non-Residential	30yr	0 (-6)	0 (-14)	0 (-24)	0 (-34)	4 (-38)	23 (-29)	38 (-27)	73 (-33)
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	5yr	0 (-9)	0 (-32)	5 (-98)	77 (-47)	105 (-37)	138 (-11)	152 (-37)	239 (-3)
Non-Residential	5yr	0 (-13)	0 (-28)	2 (-38)	44 (-17)	74 (-11)	97 (-9)	111 (2)	127 (-2)

Note: Cells highlighted in pink denote potential detrimental effect.

Detriment to 2 non-residential properties is predicted for the 1 in 200 year event for the 2100 climate change epoch. Further analysis indicates that raising the Black Lynn defence level from 4.0 mAOD to 4.2 mAOD is capable of addressing this predicted future detriment and increase total flood damage reduction benefits to just under £15 million. However, analysis suggests it is not cost-effective to implement this incremental increase in the defence design now to address future detriment; the business case for doing so will improve over time as climate change progresses, and it is therefore suggested that further raising of the Black Lynn defences is deferred for consideration in future flood risk management planning.

Combining Option 5E with the Millpark Corridor Defence option (Option 3C) is shown to be capable of achieving a 1 in 200 year minimum standard of protection for residential properties for current climate conditions. However, the incremental cost of the Millpark option is approximately 3 times the incremental benefit, such that this amendment to Option 5E is not economically viable at this point in time.

3.6.9 Summary of Combined Option Economic Performance

Table 3.26 summarises the economic appraisal outcomes in relation to each of the option combinations considered. As the leading option at the conclusion of the appraisal process, Option 5E is the preferred option for management of fluvial flood risk. This option consists of the following elements:

Option 1B: Market Street Bridge Widening
Option 2A: Lon Mor Attenuation (<10,000 m^3)
Option 2C: Mossfield Stadium Attenuation
Option 3B: Black Lynn Flood Defences(to a 4.0 mAOD minimum level)
Option 4A: Miller Road Culvert Dualling

These options are shown, in combination (Option 5E), to be capable of reducing fluvial flooding damages over the next 100 years by up to 77% or £13.8 million at a whole life cost of £8.2 million (with capital cost element of £7.6 million), achieving an overall BCR of 1.68. This option combination is predicted to increase the minimum standard of flood protection for residential properties from 1 in 5 years (currently) to 1 in 50 years for existing climate conditions, with the minimum standard of protection for non-residential properties improved from less than 1 in 2 years to 1 in 200 years for existing climate conditions.

Predicted residual fluvial-tidal flood extents following implementation of Option 5E are presented in Appendix C.

Table 3.26: Summary of economic appraisal of individual options. All costs are inclusive of a 60% optimism bias/risk contingency.

Option Label	Description	Standard of Protection to Properties			Cost & Benefit Values				Benefit-Cost Ratios			Comment
		Current Climate	2050 Climate	2100 Climate	Capital Cost (incl. 60% Optimism Bias)	Average Annual Operational Cost (incl. 60% Optimism Bias)	PV Whole Life Cost (incl. 60% Optimism Bias)	PV Whole Life Benefit	Benefit-Cost Ratio	Incremental Benefit-Cost Ratio	Increment element	
2E	Lon Mor (2A) plus Mossfield attenuation (2C)	10yr (residential) / <2yr(non-res)	2yr (residential) / <2yr (non-res)	2yr (residential) / <2yr (non-res)	£2,558,682	£12,793	£2,940,086	£6,110,997	**2.08**	**1.82**	Mossfield Stadium Attenuation (2C)	Cost-effective
2F	Mossfield (2C) plus Rugby pitches (2D) attenuation	10yr (residential) / <2yr(non-res)	5yr (residential) / <2yr (non-res)	2yr (residential) / <2yr (non-res)	£2,365,783	£11,829	£2,718,433	£4,965,033	**1.83**	**0.92**	Rugby pitches attenuation (2D)	Marginally cost-effective
2G	Lon Mor (2A), Mossfield (2C) and Rugby Pitches (2D) attenuation	50yr (residential) / <2yr(non-res)	10yr (residential) / <2yr (non-res)	5yr (residential) / <2yr (non-res)	£3,803,875	£19,019	£4,370,891	£6,829,047	**1.56**	**0.50**	Rugby pitches attenuation (2C)	Incremental cost of rugby pitch attenuation exceeds benefit; 2e preferred combination
5A	Market Street Bridge Widening (1B), plus Lon Mor (2A) and Mossfield (2C) attenuation	10yr (residential) / 2yr(non-res)	2yr (residential) / <2yr (non-res)	2yr (residential) / <2yr (non-res)	£4,718,067	£12,793	£5,099,471	£9,593,496	**1.88**	**1.24**	Mossfield and Lon Mor attenuation (2E)	Cost-effective
5B	Market Street Bridge Widening (1B), plus Lon Mor (2A) and Mossfield (2C) attenuation, plus Black Lynn Flood Defences (3A)	10yr	2yr	2yr	£5,857,705	£15,643	£6,324,048	£11,600,566	**1.83**	**1.64**	Black Lynn defences (3A)	Black Lynn defences viable and (marginally) cost-effective when combined with options which mitigate its detriment.
5C	As per 5B, with Black Lynn defences to 4.0 mAOD (i.e. 3B instead of 3A)	10yr	2yr	2yr	£6,309,771	£16,773	£6,809,807	£11,803,578	**1.73**	**0.42**	Black Lynn defences (3.8mAOD -> 4.0 mAOD)	No incremental business case for further raising defence level; 5b preferred.
5D	As per 5B, plus Miller Rd culvert dualling (4A)	50yr	10yr	2yr	£7,188,135	£18,969	£7,753,636	£12,912,864	**1.67**	**0.92**	Miller Rd culvert dualling (4A)	No incremental business case for culvert dualling; 5b preferred.
5E	As per 5D, with Black Lynn defences to 4.0 mAOD (i.e. 3B instead of 3A)	50yr (residential) / 100yr (non-res)	10yr (residential) / 30yr (non-res)	5yr	£7,640,200	£20,099	£8,239,394	£13,833,196	**1.68**	**1.17**	Miller Rd culvert dualling (4A) plus raised Black Lynn defences (3.8mAOD -> 4.0 mAOD)	In combination, raised Black Lynn defences (4.0 mAOD) and Miller Rd culvert dualling incrementally cost-effective.

3.6.10 Risks and Opportunities Associated with the Preferred Option

The following considerations should be made in relation to the preferred option, Option 5E:

All option elements:

Costing is based on civil engineering considerations only; a structural and geotechnical site assessment is recommended to determine if there are any risks which may impact the feasibility or cost of the proposed option elements (in particular, widening of the Market Street Bridge, which has been costed on the assumption the bridge must be replaced, but may have risks associated with nearby buildings and structures).

Market Street Bridge Widening (Option 1B):

The replacement bridge should be designed to achieve the maximum width and clearance possible; while existing constraints may mean that no immediate flood reduction benefit is achieved from additional width and clearance, such a design will ensure the flood damage reduction benefit of the replacement bridge is resilient to any morphological changes, partial blockage and any future schemes which widen the adjacent reach of the river.

Lon Mor Attenuation (Option 2A):

Removal of the raised ground that was historically formed to create a potential shinty pitch, but was never progressed or consented, may offer additional attenuation storage or else reduce the cost of achieving the same attenuation storage (noting that, to avoid falling under the Reservoirs Act, any modification to the design should ensure that impounded storage – excluding storage which would occur naturally even without creation of an impoundment – below spillway height does not exceed 10,000 m^3).

Mossfield Stadium Attenuation (Option 2C):

The pitch within the stadium has existing drainage, of unknown discharge path, which is not accounted for in modelling of this option. If this drainage has significant flow capacity and discharges to the river, it will alter (and may lessen) flood reduction benefits compared to predictions. This should be investigated and considered as part of detailed design if this option is progressed, in which case there may be some flood management benefit to installing a throttle on this drainage.

This option increases the depth and frequency of inundation of the car park to the north of the pitch, which is also know to receive floodwater from sewer flooding occurring on surrounding roads. The option is not predicted to inundate any known sewer entries, and so should not detrimentally impact sewer flood risk, but sewer flood volumes may displace some of the predicted benefit of this option, unless addressed by other measures.

The western section of bund would need to be integrated with existing vehicle access to the north-western corner of the stadium via Mossfield Avenue; if this is not possible, alternative access to the north-west corner of the ground exists via Glencruitten Road.

Given that fluvial flood risk is generally not forecastable – particularly the relatively short-duration events which are critical for the study area – there is a low risk of flooding of the stadium occurring while an event is taking place. While it may seem attractive to utilise deployable penstocks/sluices to allow manual control inflow and outflow of floodwater (i.e. to raise the entry spill and lower the exit spill, and therefore reduce the risk of the stadium flooding during scheduled events), this should only be considered if clear operational rules are in place, since the tendency for custodians of the stadium may be to leave the inlet closed and/or the outlet open at all times or when the site is unmanned, which would undermine the flood management benefit of this option. There is also the consideration that many outdoor sporting events are cancelled during heavy rain due for health and safety reasons.

Black Lynn Defences (Option 3B):

Raising flood walls may exacerbate sewer network flood risk associated with the backing up of river outfalls (as discussed further in Section 6.2.1). In particular, Scottish Water's network modelling predicts that two outfalls in the Lochavullin area are at risk of surcharging, which may be worsened by raised river defences, although it is also recognised that the Scottish Water model does not include the surface water pumping station in this area, which may mitigate this risk. However, modelling indicates that if raised defences are implemented as part of the preferred option combination, the overall impact of these measures is to reduce peak water levels in the Lochavullin area of the Black Lynn for a given return period.

Option costing makes allowance for piling of the western embankment in the Lochavullin area to minimise the movement of water from the river to the carpark via subsurface flowpaths when the river is in spate, with recently flood events suggesting this flow mechanism is present and may be exacerbated by "piping" (i.e. the development over time of preferential subsurface flowpaths with relatively high transmissivity).

Miller Road Culvert Dualling (Option 4A):

Existing buried utilities, and other buried object or geotechnical problems, are the primary constraint upon implementation of this option. This may alter the route or feasible shape of the culvert, or else require diversion of existing utilities; all such alterations to design may increase the cost compared to provisional estimates (although noting the high 60% optimism bias used for the purpose of costing all options). In the worst case, existing constraints may make dualling unfeasible.

Another risk associated with implementation of this option is high rainfall occurring during construction works. This could cause flooding of the trench being used to lay the new culvert line, but this risk could be minimised by protecting the upstream end of the trench until the new culvert line is complete or otherwise ensuring an open trench at the inlet is only in place for as short period of time as possible (possibly by constructing from the outlet working upstream).

Manual or CCTV inspection of the structural condition of the existing culvert should be conducted in advance of progressing dualling works, to assess its long-term viability and determine the need for maintenance/capital maintenance works, with economic appraisal assuming that the existing culvert retains full hydraulic functionality over the 100 year economic appraisal period. If inspection determines that the existing culvert is in poor condition, or else is incapable of being adequately maintained while in operation, it may be necessary to consider temporary closure of the culvert to facilitate maintenance (following completion of dualling, and using the new culvert to conduct all flow temporarily) or permanent decommissioning (in which case, the new culvert should be over-sized to achieve an increase in conveyance relative to current conditions).

3.7 Option Performance for Non-Critical Event Durations

While the performance of proposed options upon reducing predicted flood damages for the economically critical 9 hour storm event duration is appropriate for determining the cost-effectiveness of each option, it is also important to ensure that a candidate option does not cause detriment (relative to the baseline) for longer or shorter duration events, which may have a different response than the critical event to proposed changes. This is especially the case for storage-based options, which may perform well for short duration events where the provided storage volume is large relative to cumulative flow volumes within the catchment, but may have degraded performance for longer duration events where the provided storage volume becomes comparatively low against the cumulative volume of flow within the catchment.

Table 3.27 and Table 3.28 present the predicted residual damages and flood damage reduction benefit for a short-list of the likely preferred options for the 1 in 5 year and 1 in 200 year events, respectively. The analysis demonstrates that all individual options considered as part of this assessment, as well as the preferred option combination, are predicted to achieve flood reduction benefits for all event durations. Additional analysis for the Lon Mor and Mossfield Stadium options confirm that this holds for even longer (48 hour) duration events, noting that predicted baseline damages (and hence flood reduction benefits from any given option) reduce significant for progressively longer duration events beyond the 24 hour event.

Overall, this analysis demonstrates that the preferred options identified for reducing fluvial-tidal flood risk in this report are robustly effective across a range of event durations as well as return periods.

Table 3.27: Predicted 1 in 5 year event residual flood damages and flood damage reduction benefit for a range of storm event durations for preferred options

Scenario	3 hr duration	6 hr duration	9 hr duration	12 hr duration	24 hr duration
Baseline	**£93,940**	**£141,439**	**£142,577**	**£134,606**	**£90,926**
1B: Market St Bridge widening – residual damages	£48,063	£72,029	£70,961	£67,109	£45,787
Flood Damage Reduction Benefit	*£45,877*	*£69,411*	*£71,616*	*£67,497*	*£45,139*
2A: Lon Mor attenuation – residual damages	£71,061	£95,160	£94,046	£89,084	£63,886
Flood Damage Reduction Benefit	*£22,879*	*£46,279*	*£48,531*	*£45,521*	*£27,041*
2C: Mossfield Stadium attenuation – residual damages	£91,934	£134,939	£135,713	£131,072	£90,926
Flood Damage Reduction Benefit	*£2,006*	*£6,500*	*£6,864*	*£3,534*	*£0*
Option Combination 5E – residual damages	£0	£0	£0	£0	£0
Flood Damage Reduction Benefit	*£93,940*	*£141,439*	*£142,577*	*£134,606*	*£90,926*

Table 3.28: Predicted 1 in 200 year event residual flood damages and flood damage reduction benefit for a range of storm event durations for preferred options

Scenario	3 hr duration	6 hr duration	9 hr duration	12 hr duration	24 hr duration
Baseline	**£3,355,076**	**£5,454,832**	**£5,750,147**	**£5,639,047**	**£3,783,364**
1B: Market St Bridge widening – residual damages	£1,941,194	£3,051,573	£3,064,587	£2,898,057	£1,606,235
Flood Damage Reduction Benefit	*£1,413,882*	*£2,403,259*	*£2,685,559*	*£2,740,989*	*£2,177,129*
2A: Lon Mor attenuation – residual damages	£2,003,790	£3,620,498	£3,947,825	£4,039,354	£2,767,019
Flood Damage Reduction Benefit	*£1,351,285*	*£1,834,334*	*£1,802,322*	*£1,599,693*	*£1,016,345*
2C: Mossfield Stadium attenuation – residual damages	£2,318,363	£4,393,005	£3,994,193	£4,292,185	£2,864,812
Flood Damage Reduction Benefit	*£1,036,712*	*£1,061,826*	*£1,755,954*	*£1,346,861*	*£918,552*

Option Combination 5E – residual damages	£0	£220,976	£253,126	£230,359	£0
Flood Damage Reduction Benefit	*£3,355,076*	*£5,233,856*	*£5,497,021*	*£5,408,687*	*£3,783,364*

3.8 Other Benefits

In addition to reducing direct and indirect damages associated with flooding of residential and non-residential buildings, flood management options may also achieve reductions in flood consequences to traffic flow and consequential loss of productivity when routes to places of employment are cut. Flood management may also reduce the risk of injury and death associated with flood events. Due to the higher uncertainty associated with estimation of these benefits, these forms of benefit are not utilised in comparative assessment of options and are instead only estimated with respect to the preferred option combination. All analysis presented in the remaining sections of this report are therefore not inclusive of these other benefits, unless otherwise stated.

3.8.1 Reduction in Road Closure and Traffic Diversion Damages

Fluvial flooding is predicted to significantly inundate 2 roads within Oban for current climate conditions:

Lochavullin Road, along most of its length for events of 1 in 2 year return period or above (extending northwards to flood most of Lochside Street for events of 1 in 30 year return period or above).
Soroba Road, over a small section north of Miller Road for the 1 in 10 year return period event, extending to Soroba Lane for a 1 in 100 year event and beyond Market Street for a 1 in 1000 year event. With climate change, flooding of Soroba Road is predicted for the 1 in 5 year event by 2050 and the 1 in 2 year event by 2100.

In the event that Lochavullin Road was closed due to flooding, traffic which would normally be heading northwards or southwards from/to Glenshellach Road could be diverted onto Glenshellach Terrace with no net increase in travel distance – although the temporarily increased traffic volume on Glenshellach Terrace may slow average speeds. Traffic count data is not available for Lochavullin Road; on the pessimistic assumption that traffic loads are approximately 50% of those on the A85 (the nearest road for which traffic data exists; Table 3.29), estimated whole life PV damages based on traffic being slowed from 30 mph to 20 mph over a 1 km impacted length (applying values in Tables 6.11 and 6.12 of the MCH, 2019, for travel costs and indicative delay duration) are only £19k for baseline conditions, reducing to £4k with implementation of Option 5E.

Table 3.29 Average 2018 daily traffic estimate for the A85 (south of Argyll Street; ID 74341)

Travel Direction	Cars	Light Goods Vehicles	Other Goods Vehicles (OGV1; vehicles with low axle count)	Other Goods Vehicles (OGV2; vehicles with high axle count)	Public Service Vehicles (buses)
Northbound	8,855	2,268	241	82	166
Southbound	6,237	1,597	169	56	117
Total	15,092	3,865	410	138	283

Closure of Soroba Road due to flooding would be potentially more problematic to traffic flow. Traffic could be diverted westwards onto a route traversing (north to south) High Street, Glenshellach Road, McKelvie Road, and Glengallen Road, noting that these roads are not intended for high volumes of through-traffic; diversion along this route would therefore result in a longer travel route at slower speeds. Based on a conventional 1.3

km travel route at 30 mph average speed being replaced with a 2.4 km travel route at 3 mph, and assuming traffic volumes on this road are the same as those on the A85, estimated whole life PV traffic damages associated with closure of Soroba Road due to flooding are £596k for baseline conditions, reducing to £176k with implementation of Option 5E.

In combination, Option 5E is predicted to achieve a reduction in traffic-related flood consequences worth £435k (in PV terms over 100 years).

3.8.2 Reduction in Loss of Productivity Damages

Flooding of Lochavullin Road and Soroba Road will result in a loss of access to up to approximately 100 non-residential properties, including multiple shopping centres. Whether or not flooding inundates the premises, loss of access to workplaces will cause a loss of productivity. The MCH estimates the average value of a lost day's work at £87.55 (based on April 2019 average wages for the whole of the UK). Assuming the total number of employees in these businesses at any one time is approximately 570 (i.e. average of 30 for each of 6 major shops, plus average of 4 for each of 97 smaller premises), and applying values in Table 6.12 of the MCH (2019) for indicative delay to access along flooded roads, the estimated whole life PV damages associated with lost work are £321k for baseline conditions, reducing to £75k with implementation of Option 5E (i.e. a damage reduction benefit of £246k).

3.8.3 Reduction in Risk of Injury and Death

Predicted flooding in the Lochavullin area, and to a lesser degree beyond the adjacent eastern bank of the Black Lynn, reaches high depths and velocities and therefore creates a risk of injury or even death to any person within the floodwater. Specifically:

- 1 in 2 year flooding in Lochavullin (impacting the coach park, Lochavullin Road, Lochavullin Drive and section of Lynn Road west of Mill Lane) has predicted hazard ratings between "Moderate" (i.e. a danger to children and vulnerable adults) and "Significant" (i.e. a danger for most people).
- 1 in 30 year flooding in Lochavullin is predicted to cause Moderate and Significant hazard over a more extensive area, with flooding beyond the eastern bank of the river causing Significant hazard within the Lidl carpark, and Low to Moderate hazard in areas further north, south and east. Low to Moderate flood hazard is predicted in the vicinity of riverside properties in the Millpark area for this event.
- 1 in 200 year flooding extents in Lochavullin are predominantly of a Significant hazard rating, although remain Low within flooded buildings. Beyond the eastern bank of the river, Significant flood hazard is predicted in the Lidl carpark and adjacent section of Soroba Road, as well as along Miller Road and adjoining minor streets. Moderate to Significant flood hazard is predicted in the Millpark area.
- Climate change is predicted to increase the extents of flooding for a given return period, and causes higher hazards at progressively lower return periods at each location.

The UK government employs a Value of Prevented Fatality (VPF) to monetise the benefit associated with pursuing measures which will reduce the risk of death. In current prices, the VPF value is approximately £1.8 million[10], while a similar value relating to the prevention of injuries (VPI) is nominally estimated at 10% of the VPF value[11], i.e. £180k. Using these values, applied to Defra's guidance on Flood Risks to People[12], predictions of peak flooding depths and velocities at peak depth can be used to provide a monetised estimate of risk of

[10] http://bristol.ac.uk/news/2019/october/flaws-in-the-uk-vpf.html
[11] Deloitte (2009). Review of the Highways Agency Value of Life Estimates for the Purposes of Project Appraisal. A Report to the NAO.
[12] Defra (2006). Flood Risks to People. Phase 2 FD2321/TR2 Guidance Document.

injury and death for both baseline conditions and the preferred option. For the purpose of this estimate, the following assumptions were applied:

The population at risk of flooding was assumed to be directly proportional to the predicted number of flooded properties for a given event, with an assumption of 10 people at risk on average per flooded non-residential property and an occupancy rate of 2.4 (based on the UK average) per flooded residential property – noting that not all flooding has sufficient depth or velocity to pose a risk of injury or death to this population; this is simply the total population against which these hazards are quantified.

The percentage of this population assumed to be vulnerable (due to young or old age or other infirmity) was 20%. This portion of the population at risk of flooding is at risk of injury or death where flood hazard is also high.

Based on mapped predictions of the average hazard rating for each event, approximately 1-2% of the population at risk of flooding will be injured by floodwater, with between 0.1-0.2% of the population at risk of flooding potentially being seriously injured or dying due to flooding.

For baseline conditions, the monetised risk of injury or death due to flooding is estimated at £138k/yr for current climate conditions increasing to £1.04 million/yr by 2100. Over the 100 year economic appraisal period, estimated whole life damages due to injury or death are £12.9 million. With implementation of the preferred option, Option 5E, annual average injury or death damages are predicted to reduce significantly to £12k/yr for current climate conditions increasing to £386k/yr by 2100, with equivalent whole life PV damages of £4.0 million. The whole life “risk to life” benefit of Option 5E is therefore estimated at £8.89 million.

3.8.4 Summary

The preferred option combination, Option 5E, is predicted to be capable of achieving benefits in terms of a reduction traffic-related damages and a reduction in the loss of productivity (due to loss of access to workplaces) totalling £681k over 100 years (in PV terms). This would amount to a 5% increase in the predicted benefit of Option 5E, improving the BCR to 1.76. If benefits associated with reduced risk of injury and death are also included, noting that monetisation of this “risk to life” benefit is not part of standard MCH methods, the total benefits associated with the preferred option are estimated at £23.4 million, giving the option a BCR of **2.84**. However, given the higher uncertainty associated with estimation of these benefits, relative to estimates of property-related damages, some caution is needed in the interpretation of the resulting improved business case. This economic appraisal is therefore based primarily on property-related damages and damage reduction benefits only, although the degree of flood risk reduction achieved by the preferred option combination is shown by this analysis to be capable of achieving appreciable reductions in these other consequences of flooding.

3.9 Climate Change Adaptation and Long-Term Options

While the preferred option is predicted to be capable of achieving a reasonably high standard of protection for current climate change conditions, even with this investment some residential properties are predicted to be at risk from events exceeding a 1 in 10 year return period by 2050 or exceeding a 1 in 5 year return period by 2100. An estimated 88% of the £4.46 million residual flood damages over the 100 year economic appraisal period are associated with increasing flood risk over time due to climate change uplift.

The following additional measures, or modifications to proposed measures within the preferred option, are predicted to be capable of improving flood protection against climate change impacts, but lack economic justification for immediate investment:

- Implementation of flood defences in the Millpark Corridor (as per Option 3C) will improve the current and future standard of protection for those residential properties with the highest residual flood risk following implementation of the preferred option, achieving a 1 in 200 year SoP for current conditions, 1 in 30 year SoP for 2050 conditions and 1 in 10 year SoP for 2100 climate conditions.
- Combining the above with a raised Lon Mor bund crest, raised Black Lynn defences (to a 4.3 mAOD minimum crest level) and further capacity increases in the Miller Road culvert (e.g. a dual 2.1 m wide culvert) is predicted to be capable of increasing the minimum SoP to 1 in 50 years for residential properties and 1 in 100 years for non-residential properties for 2050 climate conditions, and to 1 in 30 years for residential properties and 1 in 10 years for non-residential properties for 2100 climate conditions.
- Further local protection elements in the Glencruitten Drive area are needed to achieve further improvements to the minimum SoP for residential properties for 2050 climate conditions and beyond, with similar local protection elements on the east bank of the Soroba Burn upstream of the Lynn Road bridge being needed to protect against flooding locally and further north along Soroba Road for 2100 climate conditions and thereby improve the minimum SoP for both residential and non-residential properties.

However, it should be noted that an increased reliance on engineered defence measures at multiple locations to manage flood risk in the longer term against the predicted impacts of climate change creates progressively higher peak water levels within the river and hence a progressively higher risk of failure at any given location if maintenance is inadequate, with the local consequence of defence failure being potentially severe. Noting that existing informal defence is provided by buildings which are built adjacent to the river, there is also a risk that these buildings may lack the structural strength required to withstand higher peak water levels in the river than have occurred historically. Higher defences may also create an undesirable aesthetic separation between the river and surrounding area. The problem of subsurface “piping” of flows from the river into the surrounding area when the river is in spate may also become worse, as may backflow flooding within elements of the sewer network that are otherwise designed to discharge into the river. For all of these reasons, future flood risk optioneering should aim to identify sustainable alternatives to conventional defences, including:

- Options for further attenuation of flows in rural areas upstream of Oban, such as within the golf course further upstream in the Alltan Tartach catchment.
- Alteration to operation of existing reservoirs, or repurposing and reinstatement of defunct reservoirs, to enhance floodwater storage and attenuation.
- Implementation of natural flood management measures, including reforestation, channel re-naturalisation, land management changes and wetland restoration (see Section 3.9.1).
- Replacement of existing buildings with flood-resilient buildings or lower vulnerability usages at the point of future redevelopment in areas at highest risk (along the riverside corridor and in the Lochavullin area)
- Managed retreat of development from high risk areas (particularly at the end of the operational life of existing buildings), which would allow restoration of floodplain areas and floodplain-river connections and thereby reduce the reliance on engineered defence measures for floor risk management.

3.9.1 Natural Flood Management

Natural flood management (NFM) measures are recognised as contributing to flood risk management, through one or more of:

Reducing the amount of runoff, by increasing rainfall interception and evapotranspiration, in the case of reforestation)

Detaining runoff before it reaches watercourse, by increasing depression storage and “natural attenuation” in the case of land management measures; and/or

Slowing runoff when it does occur, by lengthening flowpaths, reducing gradients and increasing the effective roughness of flowpaths in the case of channel renaturalisation and wetland restoration.

However, quantitative analysis of NFM impacts upon reducing flood risk is still a developing science. Preliminary analysis conducted as part of this study (*Report 2E: Natural Flood Management*) suggests that a 20% increase in woodland cover may be capable of achieving reductions in flow peak of between 6-13%, with the highest reduction being for small return period events.

Preliminary economic appraisal to examine the potential benefits of NFM upon reducing flood damages in Oban was conducted based on a rudimentary assumption of 5% reduction in inflows to the Glenshellach Burn, Soroba Burn and Alltan Tartach for all return periods. Analysis was conducted for NFM as a stand-alone option, as well as for NFM as an enhancement to the preferred Option 5E.

As a stand-alone option, NFM achieving an effective 5% reduction in river inflows is predicted to achieve modest reductions in the number of properties at risk of flooding for all return periods and climate change epochs, without achieving any improvement to the minimum standard of protection to properties (Table 3.30). Over a 100 year appraisal period, this is predicted to reduce flood damages by £2.6 million (15% reduction in total damages).

Table 3.30: Predicted number of flooded receptors for a stand-alone NFM scenario for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	**2yr**	**5yr**	**10yr**	**30yr**	**50yr**	**100yr**	**200yr**	**1000yr**
Residential	5yr	0 (0)	0 (0)	3 (-6)	22 (-4)	27 (-5)	45 (-2)	103 (0)	132 (-13)
Non-Residential	<2yr	1 (-1)	4 (-2)	7 (-2)	14 (-3)	22 (-2)	28 (-3)	34 (-6)	64 (-4)
Property Type	**2050 Climate Change**								
	SoP	**2yr**	**5yr**	**10yr**	**30yr**	**50yr**	**100yr**	**200yr**	**1000yr**
Residential	2yr	0 (0)	9 (-7)	27 (-1)	60 (-43)	103 (-6)	116 (-1)	129 (-14)	221 (-3)
Non-Residential	<2yr	5 (-1)	13 (-1)	19 (-5)	33 (-1)	40 (-2)	50 (-2)	63 (-2)	104 (-2)
Property Type	**2100 Climate Change**								
	SoP	**2yr**	**5yr**	**10yr**	**30yr**	**50yr**	**100yr**	**200yr**	**1000yr**
Residential	<2yr	6 (-3)	25 (-7)	100 (-3)	121 (-3)	134 (-8)	149 (0)	187 (-2)	235 (-7)
Non-Residential	<2yr	13 (0)	25 (-3)	34 (-6)	56 (-5)	85 (0)	105 (-1)	109 (0)	129 (0)

Combined with the preferred Option 5E, NFM measures achieving a 5% reduction in river inflows are predicted to improve the minimum standard of protection for residential properties from 1 in 50 years to 1 in 100 years, and similarly improve the minimum standard of protection for non-residential properties from 1 in 100 years to 1 in 200 years, for current climate conditions (Table 3.31). However, the incremental 100 year PV benefit of NFM relative to Option 5E alone is only £399k, increasing total benefits from £13.8 million (77% reduction in total damages) to £14.2 million (79% reduction in total damages).

Based on this analysis, it can be generally recommended that targeted flood management measures should be prioritised in efforts to improve the minimum standard of protection of properties to flood risk – particularly where the existing risk is relatively high, as it is for many properties in Oban. NFM should be considered as part of longer-term strategies for management and development of Oban and surrounding regions, noting that it is capable of achieving modest reductions in overall flood risk, but may not be cost-effective to implement at a large scale without also accounting for the wider ecosystem and amenity benefits of NFM which may impact the form and location of NFM measures ultimately adopted.

Table 3.31: Predicted number of flooded receptors for a scenario combining Option 5e with NFM for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to fluvial flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	100yr	0 (0)	0 (0)	0 (-9)	0 (-26)	0 (-32)	0 (-47)	6 (-97)	94 (-51)
Non-Residential	200yr	0 (-2)	0 (-6)	0 (-9)	0 (-17)	0 (-24)	0 (-31)	0 (-40)	38 (-30)
Property Type	2050 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	10yr	0 (0)	0 (-16)	0 (-28)	6 (-97)	10 (-99)	14 (-103)	91 (-52)	181 (-43)
Non-Residential	30yr	0 (-6)	0 (-14)	0 (-24)	0 (-34)	2 (-40)	16 (-36)	33 (-32)	71 (-35)
Property Type	2100 Climate Change								
	SoP	2yr	5yr	10yr	30yr	50yr	100yr	200yr	1000yr
Residential	5yr	0 (-9)	0 (-32)	2 (-101)	77 (-47)	96 (-46)	138 (-11)	146 (-43)	238 (-4)
Non-Residential	5yr	0 (-13)	0 (-28)	2 (-38)	44 (-17)	73 (-12)	97 (-9)	110 (1)	127 (-2)

Note: Cells highlighted in pink denote potential detrimental effect.

4 ECONOMIC APPRAISAL OF COASTAL FLOOD MANAGEMENT OPTIONS

4.1 Coastal Flood Extent Mapping

Explicit modelling of coastal flooding accounting for wave action is computationally intensive, and resource intensive, with the number of simulations needed to perform economic appraisal (i.e. 21 for each scenario, to cover 7 return periods each for 3 climate change epochs). Therefore a simpler approach has been adopted, using a horizontal projection methodology, which is considered appropriate in the setting of Oban due to the local topography and narrow floodplain.

Horizontal projection modelling is a GIS based approach projecting extreme sea levels onto the digital terrain model to identify areas below the extreme sea level, and determine flood depths at all receptors for a given event. Projected flood extents have been post-processed within GIS to remove areas benefitting from existing flood defences where appropriate, and to remove isolated areas of flooding where there is no obvious flow path connection to the main coastal flood extent.

Significant wave heights for the specific return period water levels have been derived from the spectral wave modelling exercise for a nearshore location adjacent to Oban. The amplitude of the significant wave has been added to the still water level to account for wave setup. Where flood walls or defences are present to a level above the calculated water level, the likelihood of wave overtopping has been assessed through review of 3D wave model results and EurOtop wave overtopping calculations (refer to *Report 2D: Oban Coastal Modelling*). Where wave overtopping is not predicted to occur the areas benefitting from flood defences have been removed from the calculated flood extent. Isolated low lying areas disconnected from the coastal waters have been removed from the calculated flood extent.

Verification modelling undertaken in Flood Modeller 2D by applying EurOtop overtopping rates as a boundary inflow indicate that inundation maps produced by GIS-based horizontal projection methodology give a reasonable representation of modelled extents; refer to *Report 2D: Oban Coastal Modelling* for further details.

4.2 Baseline Flood Risk

Maps of baseline fluvial-tidal flood risk are presented in Appendix D.

For current climate conditions, existing defences and shoreline elevations essentially ensure no coastal flood risk for events of 1 in 10 year return period or less. For 1 in 30 year conditions, limited flooding is predicted impacting the access road to the ferry terminal (around the Gallanach Road/Alma Crescent junction), the Corran Esplanade (A85) – particularly between John Street and William Street – as well an intruding onto North Pier causing some flooding of the Columba Hotel.

The 1 in 50 year return period event is predicted to cause more extensive flooding at all of the above locations, with additional flooding occurring on George Street around Argyll Street, but only impacting upon the road (i.e. no property flooding). 1 in 200 year flooding is predicted to impact the ferry and railway station area (including the railway line) and North Pier and cause flooding of Queen's Park Place, George Street (north of Stevenson Street) and the entire length of Corran Esplanade south of the Corran Esplanade, impacting properties to the east of these roads.

1 in 1000 year flooding is more extensive at all locations. Likewise, climate change is predicted to cause flooding at similar locations for progressively lower return periods, with 1 in 200 yr flooding by 2050 causing

inundation southwards beyond the railway line onto Shore Street. By 2100, a 1 in 50 year event is predicted to cause flooding of Stevenson Street and Aird's Crescent directly via the coast (i.e. even if river defences were raised to protect against corresponding tidal flooding).

Table 4.1 summarises the predicted number of flooded receptors for each return period event for each climate change epoch. For current conditions, the minimum standard of protection against coastal flooding for residential receptors is 1 in 10 years. Excepting the CalMac carpark (which is situated immediately adjacent to the shore at the southern end of the ferry terminal access road), the same minimum standard of protection applies for non-residential properties. By 2100, due to climate change, coastal flooding of residential and non-residential receptors is predicted even for the 1 in 2 year return event.

Table 4.1: Predicted number of flooded receptors for the baseline scenario for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to coastal flood risk

Property Type	Current Epoch (No Climate Change)							
	SoP	2yr	5yr	10yr	30yr	50yr	200yr	1000yr
Residential	10yr	0	0	0	4	4	5	7
Non-Residential	5yr	0	0	1	6	9	31	47
Property Type	2050 Climate Change							
	SoP	2yr	5yr	10yr	30yr	50yr	200yr	1000yr
Residential	5r	0	0	4	4	5	7	8
Non-Residential	<2yr	1	4	8	17	19	40	69
Property Type	2100 Climate Change							
	SoP	2yr	5yr	10yr	30yr	50yr	200yr	1000yr
Residential	<2yr	5	7	7	8	12	19	19
Non-Residential	<2yr	30	36	42	69	106	114	125

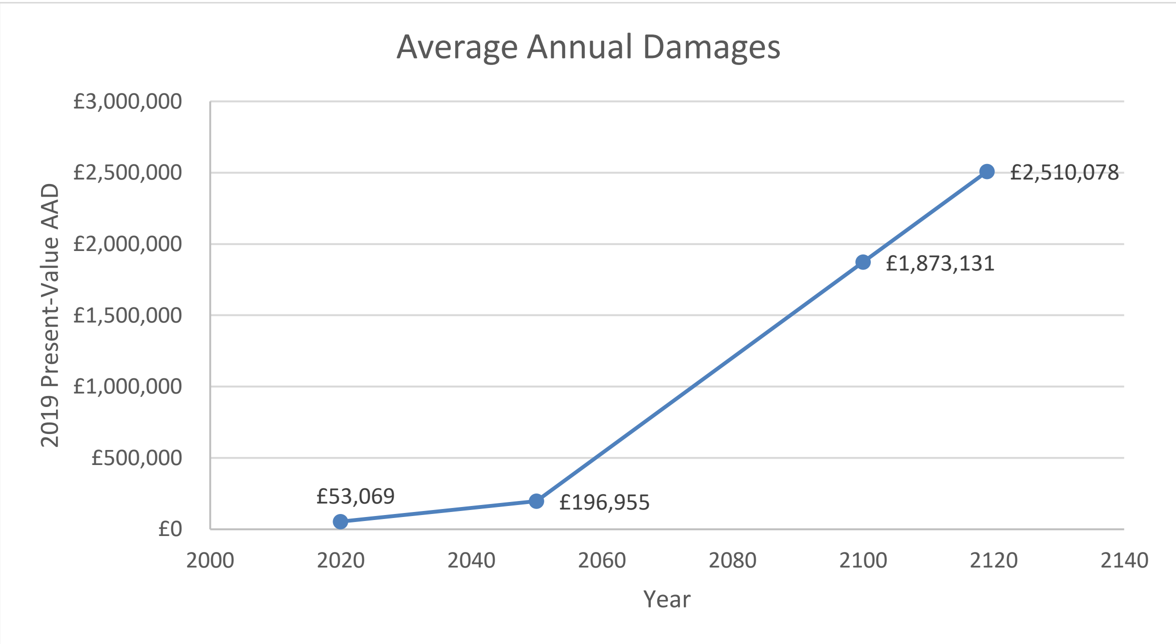

Figure 4.1: Increase in baseline average annual damages due to climate change over the economic appraisal period (i.e. Year 0 in 2020 to Year 99 in 2119)

Total present value damages over the 100 year economic appraisal period are estimated at **£10.35 million**. Predicted average annual damages (AAD) increase from £53k/yr for current conditions (without climate change) to £197k/yr by 2050 and £1.87 million/yr by 2100. Analysis extrapolates between AAD estimates for 2050 and 2100 to give an estimated AAD in the last year of the appraisal period (Year 99; 2119) of £2.51 million/yr (Figure 4.1).

4.2.1 Comparison with SEPA PVA Analysis

SEPA's PVA identifies an approximate £20k/yr AAD associated with coastal flooding between the Oban Ferry Terminal and Beacon, with the majority of damages (£17k/yr) associated with non-residential properties. The coastal flood extents considered in this study extend further south and west, with analysis indicating that approximately £48k/yr of the £53k/yr coastal AAD for current climate conditions relates to the area overlapping the PVA area. As such, while still quite small, estimated coastal damages in the current study are much greater than estimated in the PVA.

The Flood Risk Management Strategy for Highland and Argyll (2015) clarifies that coastal flooding predictions used to inform the PVA analysis are based on a simplified representation of coastal processes without an accurate representation of wave action reflecting local conditions, excepting where local models were already available for use in this analysis. There is no indication that more detailed local modelling was used to inform coastal flood predictions for the PVA analysis, and therefore it is reasonable to contend that predictions presented in this study – which are based on a local parameterisation of extreme sea level values and significant wave heights – produce damage estimates of higher confidence than those presented in the PVA.

4.2.2 Spatial Distribution of Damages

Figure 4.2 indicates that, while there are properties predicted to be at risk of coastal flooding throughout the mapped extent, the highest concentration of damages is in the vicinity of North Pier, along the A85 north and south of this pier, and in the area between the railway line and coastal boundary around the ferry terminal.

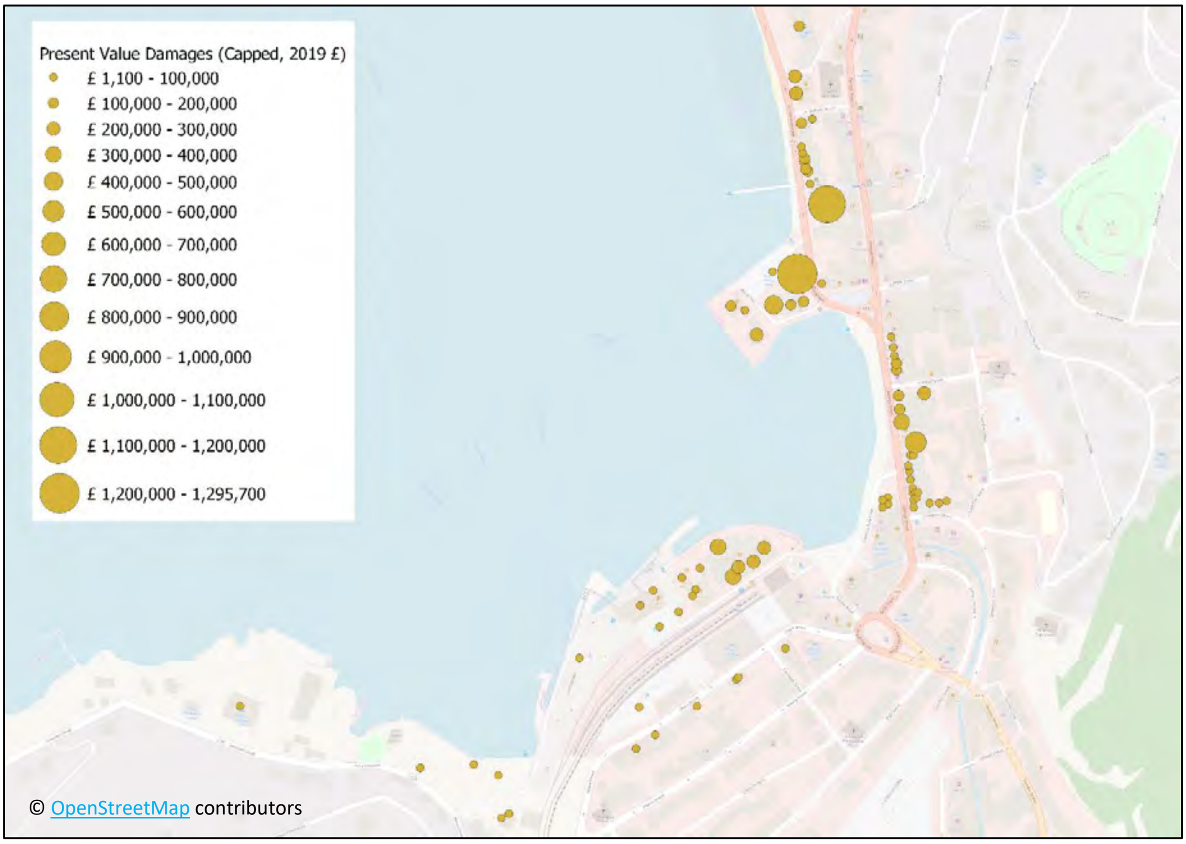

Figure 4.2: Predicted direct whole life (100 year PV) damages to properties due to coastal flooding for baseline conditions

4.2.3 Projected Damages from 2050

Note that estimated 100 year damages based on fixed climate conditions equal to current climate conditions are estimated at £1.6 million. Future climate change therefore has a significant impact upon increasing whole life damages, with 83% of the £10.35 million total value generated between the years 2050 and 2119 of the economic appraisal period. By 2050, predicted 100 year whole life PV damages due to coastal flooding are predicted to increase from the current value of £10.35 million to between £16.62 million (capped damages) and £31.51 (uncapped damages, noting that the appropriateness of applying current estimated capping values for an appraisal period commencing in 2050 is uncertain).

4.2.4 Other Forms of Damage

Coastal flooding may also cause economic damages beyond direct and indirect damage due to property flooding. Coastal flooding may also result in economic damages through road closure and traffic diversion, loss of productivity when access to workplaces is lost, as well as damages relating to risk to life (see Section 3.8 as these relate to fluvial flooding).

<u>Traffic Damages</u>

For the 1 in 30 year event or above, coastal flooding is predicted to inundate parts of the coastal (northward) section of the A85 north of John Street. This would likely necessitate diversion of northbound traffic onto Hill Street (and from there on to, in turn, Rockfield Road, Ardconnel Terrace, Ardconnel Road, Dalriach Park Terrace, Dalriach Road and Deanery Brae), necessitating a longer travel route at slower average speeds. Climate change to 2100 is predicted to inundate Stevenson Street for events of 1 in 50 year return period or above, resulting in the loss of a north-south road connection within the Oban townsite. In this scenario, traffic approach from or heading to the south of Oban must be directed onto Glencruitten Road and the adjoining single-lane road, the north end of which joins the A85 to the west of Connel. Traffic approach from or heading to Kilmore (or locations further south) may similarly be diverted onto the single-lane road passing Loch Nell, which also terminates at Connel (noting that these diversion routes assume coastal flood risk does not inundate the A85 within or around Connel). Based on a 2 km extent of slowed/diverted traffic for current coastal flooding above the 1 in 30 year event and a 10 km extent of slowed/diverted traffic when Stevenson Street is flooded, estimated whole life PV traffic damages due to coastal flooding are £49k. Given the relatively small magnitude of these damages, and the high uncertainty associated with their estimation, these damages are not considered any further in this economic appraisal of coastal flood management.

Loss of Productivity Damages

On the assumption that the average number of employees in each flooded non-residential receptor is 4 at the time of flooding, and based on a UK average daily wage of £87.55 (see Section 3.8.2), the estimated whole life PV damages due to loss of worker productivity is £46k. Given the relatively small magnitude of these damages, and the high uncertainty associated with their estimation, these damages are not considered any further in this economic appraisal of coastal flood management.

Risk of Injury and Death

While coastal flooding is predicted to inundate a high number of properties for higher return period events, the risk of injury or death due to coastal flooding is considered to be low, as this form of flooding is generally forecastable, and impacted areas (and especially vulnerable people) can be evacuated. There is a residual risk of injury or death where individuals don’t receive or respond properly to warnings and preparations, including tourists and people in transit from other locations, as well as emergency responders who may be required to place themselves at risk. However, it is difficult to quantify or monetise this risk, and it is therefore not estimated in this analysis.

Summary

Baseline coastal flooding damages due to traffic diversion and delays, plus loss of access to workplaces, is estimated at approximately £95k (in PV terms over 100 years). This amounts to less than 1% of property-related damages, such that these forms of damage are not analysed further in this appraisal of coastal flood management. Likewise, as coastal flooding generally forecastable, the risk of injury and death due to coastal flooding is considered to be minimal, and this risk is not monetised in relation to coastal flooding for this appraisal. As such, total flood damages (and damage reduction benefits) are essentially equal to property-related flood damages (and damage reduction benefits).

4.3 Assessment of Coastal Defence Options

4.3.1 Option 6A: Extensive Defence Option

This option entails construction of new or raised defences from the eastern end of the existing defence wall located around the Black Lynn outfall to a point beyond the Corran Esplanade roundabout, consisting primarily of vertical walls, integrating flood gates to maintain existing pedestrian and slipway access points. As an operational area, protecting the ferry terminal and surrounding area with engineered defences would have undesirable potential detrimental consequences upon existing usage which cannot be readily quantified; as such, it is not proposed to protect this area. Coastal damages further west of the ferry terminal are predicted to be small and sparse, such that it can be stated without detailed analysis that defence of this area would not be economically justifiable. The proposal is based on a defence level of 4.67 mAOD, corresponding to the predicted 1 in 200 year peak (stillwater) sea level for climate conditions in the year 2100 (i.e. accounting for predicted sea level rise associated with climate change).

The estimated capital cost of this option is between **£4.62 million** and **£7.69 million**, depending upon whether defences can be located adjacent to the A85 (Corran Esplanade) or else whether land reclamation is needed to ensure a buffer is maintained between the road and construction works. Accounting for maintenance costs over the economic appraisal period (which includes for capital investment to restore full functionality to the defences during the 100 year economic appraisal period, noting that coastal defences are typically expected to significantly degrade over a 30-60 year period, depending upon the quality of initial construction, degree of wave force and effectiveness of maintenance; EA/Defra provide some guidance on this[13]), the estimated whole life (Present Value) cost of the extensive coastal defence option is between £5.19 million and £8.64 million.

Flood damage analysis predicts that the proposed defence option is capable of improving the minimum standard of protection (with respect to coastal flood risk) for residential properties to 1 in 200 years (Table 4.2), with the option generally protecting properties from flooding for current climate conditions. All properties behind the proposed defences are predicted to be completely protected (with an effective 1 in 1000 year Standard of Protection) for current climate conditions, with residual flood risk associated with undefended locations further south. However, sea level rise due to climate change poses a risk to properties behind proposed defences, with a predicted minimum standard of protection of 1 in 50 years by 2050 a 1in 5 years by 2100.

The predicted whole life (PV) benefit of this option in reducing coastal flood damage is estimated at **£4.86** million over the following 100 years. With consideration of the cost range for this option, it can be concluded that the extensive coastal defence option is unlikely to economically viable unless substantial cost savings can be realised, possibly including site investigation and cost consultation aimed at determining a site-specific risk contingency cost value to replace the 60% optimism bias assumed for costing here. Alternatively, this option could be deferred noting that, as baseline damages increase with time due to climate change, the economic viability of defending this extent of coast may improve (Section 4.2.3).

Table 4.2: Predicted number of flooded receptors for the extensive coastal defence option for each modelled return period and climate change epoch, along with the minimum Standard of Protection (SoP) with respect to coastal flood risk. Change in number of receptors relative to baseline shown in brackets.

Property Type	Current Epoch (No Climate Change)							
	SoP	2yr	5yr	10yr	30yr	50yr	200yr	1000yr
Residential	200yr	0 (0)	0 (0)	0 (0)	0 (-4)	0 (-4)	0 (-4)	2 (-5)
Non-Residential	5yr	0 (0)	0 (0)	1 (0)	1 (-5)	2 (-7)	2 (-7)	14 (-33)
Property Type	2050 Climate Change							
	SoP	2yr	5yr	10yr	30yr	50yr	200yr	1000yr
Residential	50yr	0 (0)	0 (0)	0 (-4)	0 (-4)	0 (-5)	7 (0)	8 (0)
Non-Residential	<2yr	1 (0)	1 (-3)	1 (-7)	4 (-13)	8 (-11)	40 (0)	69 (0)
Property Type	2100 Climate Change							
	SoP	2yr	5yr	10yr	30yr	50yr	200yr	1000yr
Residential	2yr	0 (-5)	2 (-5)	7 (0)	8 (0)	12 (0)	19 (0)	19 (0)
Non-Residential	<2yr	10 (-20)	13 (-23)	42 (0)	69 (0)	106 (0)	114 (0)	125 (0)

[13] Environment Agency (2009). Guidance on determining asset deterioration and the use of condition grade deterioration curves.

4.3.2 Option 6B: Reduced Extent Defence Option

The spatial distribution of predicted direct property benefit due to the extensive coastal defence option is illustrated in Figure 4.3. This indicates that:

- No properties adjacent to the northernmost two sections of proposed defence (Sections 1 and 2) are predicted to be currently at risk of tidal flooding, and therefore receive no benefit from proposed defences.
- Only a single property adjacent to Section 3 benefits from this proposed defence section.
- Multiple properties, some to a very large monetary value, benefit from Sections 4-6 of the proposed defence.

Figure 4.3: Predicted direct whole life (100 year PV) damage reduction benefit to properties from the extensive defence option

Table 4.3 presents further analysis of the spatial distribution of benefit against capital cost, indicating that whole life benefits exceed capital cost estimates for defence sections 4-8 (although noting that costs don’t include for maintenance costs over the economic appraisal period). While Section 3 achieves a sizeable benefit, costs for construction of this section are significantly greater.

Table 4.3 Sectional analysis of capital cost against whole life direct damage reduction benefit for the extensive defence option

Section	Estimated Capital Cost	Estimated Direct Property PV Benefit
Proposed Defence Section 1 (Corran Halls to Victoria Crescent)	£635,773	£0
Proposed Defence Section 2 (Victoria Crescent to south of Great Western Hotel)	£653,505	£0
Proposed Defence Section 3 (South of Great Western Hotel to William Street)	£635,773	£357,674
Proposed Defence Section 4 (William Street to north of North Pier)	£777,113	£1,362,250
Proposed Defence Section 5 (North Pier to Cuan Mor restaurant; including pier)	£1,105,461	£1,674,480
Proposed Defence Section 6 (Cuan Mor restaurant to Black Lynn outfall)	£766,458	£1,034,900

On the basis of this preliminary appraisal, a partial coastal defence option consisting of Sections 4-8 only may be an economically viable option to significantly reduce coastal flood risk in Oban north of the Black Lynn outfall. The defence would tie into existing high ground at its southern end. However, an engineered tie-in would be necessary to prevent flooding around the northern end of Section 4 of the defence, which would be difficult to implement in this location. The most logical location to achieve tie-in is at the northern end of Section 3, corresponding to the location of the existing property boundary wall between the Esplanade Court apartments and Great Western Hotel. Given that coastal flooding is forecastable, and flood warnings would advise that all traffic avoid this section of the A85 during a coastal flood warning, it would be feasible to achieve tie-in using a deployable flood gate across the A85, and costing for this option is based on this. Alternatives, including further raising of the road level are possibilities, however, the mechanism for achieving tie-in should be discussed and agreed with all relevant stakeholders, including Transport Scotland, as part of detailed design of this option if progressed.

Inclusive of costs for a flood gate at the northern end of the protected extent, the estimated capital cost of a reduced extent option covering Sections 3-8 only is £3.46 million (based on the cheaper option variant, with new defences constructed upon or adjacent to the existing defence line, without land reclamation), with an estimated whole life cost (inclusive of allowance for major capital maintenance of the defences after 50 years) is **£3.89 million**. With total estimated whole life PV benefits of **£4.78 million**, the estimated BCR of this option is **1.23**. As this option protects all properties predicted to benefit from the extensive defence option, the impact of this option upon the number of receptors at risk from a given event is the same as for the extensive defence option, as presented in Table 4.2.

Note that costing for the reduced extent option assumes no land reclamation is required to site the new defences, and instead that defences can be constructed upon the existing defence line or else upon the public footpath immediately inland of the existing defence line. As such, there is a significant cost risk associated with progressing this option if detailed design, stakeholder consultation or site investigation indicates that a significant extent of proposed defences must instead be located on the seaward side of existing defences which is not accounted for in optimism bias. Transport Scotland may object to extensive construction works in close proximity to a trunk road, but it is proposed that associated traffic and pedestrian safety risks are addressed through traffic management and temporary footpath closure measures during construction. If, however, these mitigations are considered to unacceptable, there is a risk that this option may ultimately not be economically viable. Stakeholder engagement will therefore be an important consideration if this option is progressed.

4.3.3 Property Level Protection

If progression of the reduced extent defence option is considered to be too risky or economically marginal, an alternative strategy may be to defer progression of engineered defences until such a time as increased coastal flood risk due to climate change impacts makes the business case for these defences overwhelming and instead focus immediate investment on property level measures for the small number of properties which are currently at high risk of coastal flooding (Figure 4.4). The following properties are predicted to flood for the 1 in 30 year coastal event for current climate conditions:

- The Columba Hotel, including the 4 commercial premises within the same building footprint.
- 4 No. ground-floor flats at 22-24 Alexandra Place.
- Ground floor offices at 26 Alexandra Place.

Three properties are predicted to flood for the 1 in 50 year coastal event for current climate conditions:

- The Oban Chocolate Factory shop at 34 Corran Esplanade.
- Coasters public house at 38 Corran Esplanade.
- The Whisky Cellar on Corran Esplanade (noting that this building was not within the receptor database data on which economic appraisal was based; flood reduction benefit calculations therefore do not include benefits associated with protecting this property).

Figure 4.4 Properties targeted for Property Level Protection against coastal flood risk (red outline), with 1 in 50 year coastal flooding extents shown (grey shading)

It is inappropriate to assess benefits associated with property level protection (PLP) measures over a 100 year economic appraisal period, as the operational life of these measures is typically much lower, with no guarantee that PLP remains the most suitable form of flood management for these properties when it comes time for replacement or major repair. Based on a more appropriate 25 year economic appraisal period, and assuming PLP measures are only effective to a depth of 0.6m, whole life PV damages to these properties is predicted to reduce from £1.06 million to £70k due to PLP measures (noting that damages to individual properties are below market values in all cases, such that capping of damages does not impact this estimate, and noting again that this value does not include for flood reduction benefits to the Whisky Cellar). However, the MCH advises that the estimated benefit from PLP should be factored by 0.84 to account for the risk of residual flood damages associated with incomplete water sealing or other potential inadequacies in installation, operation or maintenance of PLP measures, such that for the purposes of economic appraisal the estimated benefit of PLP for these properties is £830k. By comparison, the whole life PV cost of PLP measures for these properties is estimated at £407k (with £375k capital cost), such that targeted protection of these properties is predicted to be cost-effective (i.e. BCR of 2.04, with a higher BCR if the Whisky Cellar is included in benefit calculations).

4.4 Summary

Preliminary design of engineered coastal defences for the area north of the Black Lynn has been undertaken and costed, with economic appraisal conducted to determine flood damage reduction benefits. Analysis predicts that defences to a minimum level of 4.67 mAOD between the southern end of the Great Western Hotel boundary and the existing defensive wall at the Black Lynn outfall are capable of achieving a 100 year (PV) flood damage reduction benefit of £4.78 million at a (PV) cost of £3.89 million, achieving a BCR of 1.23. However, there are significant unknowns associated with the design and costing of this option; if some or all of these are realised (particularly if it is ultimately necessary to site proposed defences on the seaward side of existing defences), costs may rise significantly. Based on these risks, the business case for progressing this option is therefore considered to not be robust – especially given that existing defences are predicted to offer a reasonable standard of protection against coastal flooding for all but a small number of properties for current climate conditions.

It is therefore recommended that investment in engineered coastal defences is deferred, noting that predicted coastal flood damages are expected to significantly increase beyond 2050, such that the business case for coastal defence investment will become more compelling and robust with time. In the meantime, flood management should focus upon improving flood resilience to a small number of properties at highest risk, with property level protection measures for these properties predicted to be cost-effective.

5 ECONOMIC APPRAISAL OF SURFACE WATER FLOOD RISK

In the absence of an available surface water network model for Oban for use in this study, economic analysis of surface water flood risk is restricted to a consideration of predicted flood map data provided by Scottish Water. Flood extent maps, based on minimum peak flood depth thresholds of 1 mm, 100 mm and 300 mm, were provided by Scottish Water for the 1 in 1, 2, 5, 10, 30, 50, 100 and 200 year return period events for both a 1 hour and 3 hour event duration for current climate conditions. This data is insufficient to clearly indicate the maximum depth of flooding at each receptor point, and hence cannot be used for full depth-damage analysis. However, the effective standard of protection of each receptor can be determined and used to determine a high-level estimate of flood damages based on the Weighted Average Annual Damage (WAAD) method. As the Scottish Water network model covers all of the Oban catchment, estimates based on sewer flooding can reasonably be used as a proxy for overall surface water flooding. However, note that Scottish Water flood mapping is based on the assumption that sewer outfalls into watercourses and coastal waters are free-draining; it therefore represents flooding caused purely by capacity limitations in the network, and does not account for flooding induced by locking or backflow at sewer outfalls which may occur when the river is in spate and/or during high tides, nor for existing mitigation to this risk provided by surface water pumps located in the Lochavullin area.

Scottish Water's predicted flood maps are based on 2D manhole flooding predictions using a LiDAR ground model, with no allowance for building upstand. As the average property upstand based on limited threshold surveying is approximately 300 mm, it is reasonable to exclude predicted flooding of below 100 mm peak depth from analysis. Conversely, the lack of building upstand in Scottish Water analysis may falsely under-estimate the depth of flooding which may "back up" against a raised building; as a precaution against this, analysis is based on 100 mm depth threshold data.

Table 5.1 presents the total number of receptors points at locations predicted by Scottish Water modelling to be inundated to at least a 100 mm depth for each modelled return period; values shown are for the 1 hour event duration, noting that the receptor count is lower in all cases for the 3 hour event duration. This analysis indicates that, based on model predictions, 1 residential property is at risk of sewer network flooding in response a 1 in 5 year storm (i.e. an estimated 1 in 2 year Standard of Protection), with an additional residential property and 2 commercial properties at risk from a 1 in 10 year storm (i.e. 1 in 5 year Standard of Protection), and a total of 10 properties at risk from a 1 in 30 year storm (i.e. 1 in 10 year Standard of Protection). The location of these 22 receptors at risk is presented in Figure 5.1. By comparison, similar analysis based on a 300 mm depth threshold indicates that only 3 receptors are at risk of sewer flooding for the 1 in 200 year event.

Table 5.1 Number of receptors predicted to be flooded by sewer flooding for a 1 hour duration event (based on a 100 mm depth threshold). WAAD values are based on "no warning" values from the MCH (2019).

Return Period (1 in x years)	Effective Standard of Protection (SoP) (1 in x years)	Per-property WAAD Value (MCH, 2019)	Residential Receptor Count	Non-Residential Receptor Count	Total Receptor Count
1	No protection	£5,297/yr	0	0	0
2	No protection	£5,297/yr	0	0	0
5	2	£5,297/yr	1	0	1
10	5	£3,219/yr	2	2	4
30	10	£1,656/yr	6	4	10
50	30	£793/yr*	8	5	13
100	50	£84/yr	11	7	18
200	100	£43/yr	13	9	22

** Note: No WAAD value available for a 1 in 30 yr SoP; 1 in 25 yr value used.*

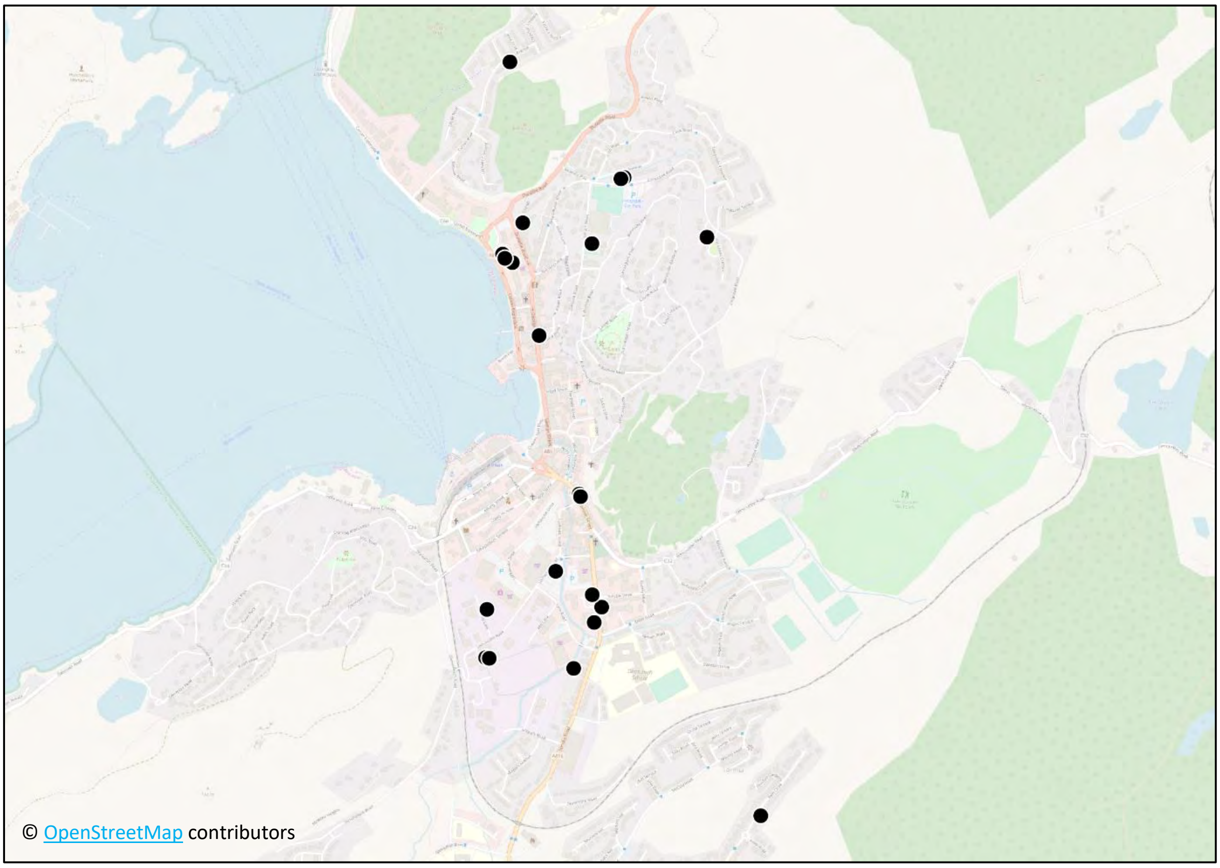

Figure 5.1: Location of properties where Scottish Water network flood depths are predicted to exceed 100 mm for a 1 in 200 year event

Based on 2019 WAAD values provided by the MCH, the total estimated WAAD for sewer flooding is **£29,295/yr** for current climate change conditions. Ignoring potential double-counting of damages to receptors from more than one source of flooding, surface water flooding is therefore estimated to account for approximately 10% of total flood damages in Oban, compared to 71% fluvial-tidal flood damages and 19% coastal flood damages.

Similar modelled predictions of sewer flooding are not available for future climate change epochs. On a crude assumption of a comparable proportional increase in sewer flood damages due to climate change as predicted for fluvial-tidal flooding, the estimated whole life 100 year PV damages associated with surface water flooding is approximately **£3.0 million**.

Noting the relatively small value of estimated damages and large uncertainty in methodology, and noting also that Scottish Water do not identify any properties in Oban as being at risk of internal sewer flooding up to their required level of service (i.e. a 1 in 30 year return period event), it is concluded that there is insufficient evidence to support a business case for immediate investment to address this source of flooding. It is therefore not recommended that any specific measures are immediately progressed to protect the 22 receptors identified as being at potential risk of surface water flooding from this analysis. Instead, a longer-term strategy for minimising the risk of surface water flooding is recommended, to be progressed in collaboration with Scottish Water and other stakeholders, as presented in *Report 2C: Surface Water Management Plan*.

However, noting again that the above analysis does not account for flooding induced by locking or backup of sewer outfalls when water levels in the receiving water (i.e. within the river or in coastal waters) are high, damages associated with sewer flooding may be higher than estimates presented above – especially in the low-lying areas bordering the Black Lynn. It is therefore important to ensure that fluvial and coastal management options do not increase peak water levels in the receiving water and therefore exacerbate this source of flood risk; this is considered further in Section 6. Furthermore, it remains important to maintain and monitor the performance of the existing surface water pumps in the Lochavullin area, to ensure their effectiveness, and determine if further pumping capacity (here or at other locations) is required to better manage this form of interacting flood risk.

6 MULTI-SOURCE FLOOD INTERACTION

Interaction between fluvial-tidal flooding and coastal flooding has been assessed as part of this study as minor (refer to Section 2.6). Due to the lack of an available model, interaction between surface water flooding and either fluvial-tidal or coastal flooding cannot be quantified. However, qualitative statements can be made in relation to multi-source flood interaction, and these are summarised in the sections below.

6.1 Interaction Between Coastal Flooding and Surface Water Flooding

Coastal defence options considered as part of this study do not have any impact upon sea level and wave heights at existing coastal outfalls; therefore, the impact of these options upon exacerbating network flooding due to tidal locking will be neutral. In this sense, the impact of proposed coastal options upon potentially exacerbating surface water flood risk is restricted to the potential blockage of spill pathways for surface water to discharge overland into the sea during conditions in which coastal flooding would not otherwise occur without proposed defences. Within the area to be protected by Option 6B, Scottish Water modelling indicates surface water flooding currently discharges overland to the sea at:

- Breadalbane Street (near the Coasters bar) for events of 1 in 5 year return period and above (noting that coastal flooding is predicted at this location for events of 1 in 50 year return period and above for the baseline scenario);
- At the southern end of Corran Esplanade for events of 1 in 30 year return period and above (noting that coastal flooding is predicted at this location for events of 1 in 1000 year return period and above for the baseline scenario);
- At numerous locations between Queen's Park Place and the Esplanade Court Apartments for events of 1 in 100 year return period and above (with coastal flooding triggered along this extent for return periods between 1 in 50 years and 1 in 1000 years, depending upon exact location).

In all cases predicted surface water flooding depths are quite low (below 100 mm), with the likelihood that gully entries along coastal roads (i.e. Queen's Park Place, George Street and Corran Esplanade) – which are not explicitly represented in sewer network modelling – will provide a pathway for discharge of this floodwater whenever sea levels fall below ponded water levels on these roads. Gullies will remain functional in this respect (i.e. have a positive hydraulic gradient to discharge surface water flooding into the sea) at low to moderate return periods (below 1 in 50 years) at all locations, regardless of proposed defences. At moderate to high return periods, surface water discharge overland or via gullies being “locked” due to higher sea levels regardless of whether proposed defences are progressed. As such, the impact of proposed defences upon surface water flood accumulation along coastal roads is likely to be neutral, with no specific mitigation required other than maintenance of (and clearance of blockage from) coastal outfalls and gullies along coastal roads.

6.2 Interaction Between Fluvial-Tidal Flooding and Surface Water Flooding

6.2.1 River defence options

Conventional river defence options generally have the impact of increasing local peak river water levels (as well as prolonging the persistence of high water levels) for a given return period event, which may exacerbate “locking” of any river outfalls and may increase backflow flooding for any outfalls which lack a non-return valve. Depending upon what the critical constraints are causing flooding with the sewer network, and the location and design of river outfalls, river defence options may worsen network flood risk or else be neutral with respect to network flood risk. The volumetric rate of river flooding being defended against is usually far greater than the volumetric rate of sewer discharge to the river, such that the fluvial flood reduction benefit will normally far outweigh any network flooding detriment, but detailed design may nonetheless need to include mitigation of "secondary flood risk" associated with river outfalls to ensure no individual receptors are at greater overall flood risk due to river defence options.

Scottish Water's network model identifies the following outfalls in the Black Lynn:

3 outfalls in the vicinity of the Lynn Road Bridge, upstream of the confluence with the Alltan Tartach
2 outfalls on the lower Alltan Tartach adjacent to Soroba Road
1 outfall adjacent to Lynn Road (at the southern end of Lochavullin)
1 outfall in Lochavullin
3 outfalls between the Soroba Lane and Market Street bridges
1 outfall between the Market Street bridge and A816
3 outfalls between the A816 and coastal outfall of the river

For a river defence option in isolation (i.e. Option 3A or 3B), it would be expected that peak water levels would increase at all 14 of these outfalls. However, for the preferred option combination, modelling predicts that peak water levels are lower (typically by between 100-400 mm) than for baseline conditions for all return period events and climate change epochs for all locations upstream of the Market Street Bridge. As such, for 10 of the 14 outfalls, the impact of the preferred option combination will be to reduce the risk of surface water flooding due to backup at outfalls. Depending upon whether this is an important mechanism causing surface water flooding, the overall impact of the preferred option combination upon surface water flood risk will either be neutral or beneficial in locations upstream of the Market Street Bridge.

Downstream of Market Street Bridge, the tidally-dominant joint probability realisation is critical in determining worst-case peak water levels and flooding. In this location, the preferred option combination is predicted to result in small peak water level increases of up to 30 mm for some, but not all, modelled return periods relative to baseline predictions. Given that there is no clear pattern in this behaviour, it is likely that predictive differences in this location are being impacted by the tidal-fluvial phasing used in analysis, which is based on critical (i.e. worst-case) timings for the Lochavullin area for baseline conditions, and therefore may differ slightly from critical timing further downstream and may also be slightly impacted by the proposed widening/replacement of the Market Street Bridge. Given the small magnitude of the predicted increases, and the likelihood that these increases essentially are caused by a limitation of the modelling approach, it is concluded that it is likely that the preferred option combination will have a neutral impact upon surface water flood risk downstream of Market Street Bridge.

6.2.2 Upstream attenuation options

Upstream attenuation option have the impact of reducing peak water levels in the downstream urban reaches of the river, and therefore tend to have a beneficial impact upon surface water flood risk, by reducing the risk of locking and backup of river outfalls. However, if upstream attenuation options have the impact of increasing water levels upstream of the throttle/embankment location, there is a risk of increased backup if there are any sewer outfalls within the impacted river reach. More generally, if the area where water is being temporarily stored has any direct or direct drainage connections to the sewer, these connections can undermine the benefit of the option, by passing increased flood risk to the sewer system (which may be returned to the river anyway via outfalls).

The Mossfield Stadium and carpark area is not indicated to contain any sewer manholes or pipes based on the Scottish Water model. However, it may have secondary connection points (not represented in the model), used to enhance drainage of the pitches. It is important that any such connections are identified during detailed design of this option, and throttled if necessary to prevent excessive "leakage" of the intended attenuation storage into the sewer (noting that some residual drainage via the sewer may be necessary to prevent waterlogging of the pitches just below ground level). Where some drainage capacity to the sewer is retained, the impact of this upon sewer flood risk should be evaluated and the design of the intended outflow structure and spillway modified (i.e. reduced in overall capacity) to correct for this impact.

There are 2 Scottish Water sewer outfalls into the Glenshellach Burn within the proposed attenuation area for Option 2A, which will therefore be at risk of increased backup due to the preferred option. For current climate conditions, 1 in 30 year peak water levels in the Lon Mor floodplain area are predicted to increase from 7.3 mAOD to 7.8 mAOD and 1 in 200 year peak water levels from 7.6 mAOD to 8 mAOD. By comparison, the two sewer outfalls drain Glengallen Road and Park Road, which have surface levels as low as 9 mAOD and therefore may have sewer pipes with soffit levels as low as 7.5 mAOD (based on recommended minimum burial depths of 1.5 m for pipes under roads). While there is a risk that increased backup of outfalls caused by the Lon Mor option could exacerbate the risk of sewer surcharge and possibly surface water flooding for moderate to higher return period events, it should be noted that any surface water flooding in the area will flow overland towards and into the Lon Mor area in any case. It is therefore recommended that these outfalls be fitted with non-return valves (if not already equipped) to avoid backflow risk. Otherwise, no specific mitigation is recommended as being required to address this impact.

Note that upstream attenuation can increase the persistence of higher-than-normal water levels in the river downstream following the attenuated peak, but for the options considered as part of this appraisal this “persistence” is shown to occur at relatively low water levels, within 300 mm of baseflow water levels in the urban reach of the Black Lynn; as such, it is very unlikely to detrimentally impact sewer flood risk.

6.3 Summary

The potential for interaction between different sources of flooding to either impact option development or to result in an option causing “secondary flooding” detriment (i.e. reducing flood risk from the targeted source, but increasing flood risk from another source) is assessed to be negligible or minor in all cases. This is summarised for each potential source of interaction as follows:

- The interaction between coastal and fluvial-tidal flooding extents is assessed to be minor, relating to properties which account for approximately 1% of overall fluvial-tidal damages. Likewise, options aimed at managing fluvial-tidal flood risk will have no impact upon sea levels and therefore upon coastal flood risk, and *vice versa*.
- While some surface water flooding is predicted to flow overland into the sea, this water is likely to also drain via coastal road gullies, which are not accounted for in modelling. Proposed coastal defences do not alter the sea level at coastal outfalls, and therefore will not alter drainage of surface floodwater via gullies. As such, the impact of coastal flood management options upon altering surface water flood risk can be reasonable discounted.
- Similarly, while proposed fluvial-tidal flood management options may pose a theoretical risk of increasing flooding associated with sewer locking and backup at river outfalls, the preferred option combination is predicted to achieve overall reductions in peak river water levels for any given return period, and therefore have a neutral or beneficial impact upon sewer flood risk. While raised defences may act as a barrier to overland surface water flows discharging into the river, it should be noted that proposed reach of defences are already currently defended to a lower level by banks, building walls and informal protection features, such that the impact of raised defences is likely to be neutral, and any minor detriment could be addressed by the provision of drainage points (fitted with non-return valves) at the base of proposed walls and embankments to permit drainage through these defences when river levels are low.
- The Lon Mor attenuation option may increase the risk of surface water flooding associated with 2 outfalls into the Glenshellach Burn, however topographic gradients will ensure that any resultant flooding will discharge into the Lon Mor depression (i.e. the same fate as the discharge from the

outfalls). As such, while it is recommended that the two outfalls in question are fitted with non-return valves, no wider mitigation is recommended.

7 CONCLUSIONS AND RECOMMENDATIONS

Fluvial-Tidal Flood Risk Management

Present value property-related damages due to river flooding in the Oban area (inclusive of tidal flooding from the Black Lynn) are estimated at £17.9 million over the next 100 years, with climate change predicted to cause a significant increase in the depth and extent of flooding and hence resultant damages. The following options have been examined and are recommended for further consideration, design and optimisation as part of a strategy for managing this risk:

Option 1B: Market Street Bridge Widening
Option 2A: Lon Mor Attenuation
Option 2C: Mossfield Stadium Attenuation
Option 3B: Black Lynn Flood Defences (to a minimum 4.0 mAOD crest level)
Option 4A: Miller Road Culvert Dualling

Noting that the latter two option elements are capable of causing detriment downstream in isolation, construction phasing should ensure that upstream attenuation elements (Mossfield Stadium and Lon Mor attenuation) are constructed in advance of the culvert dualling and flood defence elements.

These options, in combination, are predicted to reduce whole life fluvial-tidal property-related flood damages in Oban by 78% (£13.8 million) over the next 100 years. Other benefits, including reduction in traffic-related damages (i.e. road closure and traffic diversion and delays due to flooding), reduction in loss of productivity (i.e. loss of access to workplaces due to road flooding), and reductions in the risk of injury and death due to flooding, may provide up to £9.6 million of additional benefit from the preferred option combination.

Residual whole life damage amounts to £4.46 million, with approximately £4 million (88%) of this value being associated with future increases in flood risk due to climate change. Additional flood defences in the Millpark Corridor (i.e. Option 3C), additional attenuation storage in Lon Mor (i.e. enhancement of Option 2A), further increases in the height of the Black Lynn defences in combination with further increases to the capacity of the Miller Road culvert (i.e. enhancements of Options 3B and 4A), along with local protection elements in the Glencruitten Drive and Lynn Road Bridge areas are predicted to be capable of significantly improving the minimum standard of protection for the 2050 and 2100 climate change epochs, but are not cost-effective for immediate investment. Instead, these options should be considered as part of longer-term flood management planning for Oban, along with a wider array of options including:

Natural flood management, in one or all of the Glenshellach Burn, Soroba Burn, or Alltan Tartach watercourse catchments.

Further flood attenuation in the upper reaches of the Alltan Tartach, for example within the Glencruitten Golf Course.

Alteration to the operation of existing reservoirs, or repurposing and reinstatement of defunct reservoirs, to enhance floodwater storage and attenuation.

Replacement of existing buildings with flood-resilient buildings or lower vulnerability usages at the point of future redevelopment in areas at highest risk (along the riverside corridor and in the Lochavullin area)

Managed retreat of development from high risk areas (particularly at the end of the operational life of existing buildings), which would allow restoration of floodplain areas and floodplain-river connections and thereby reduce the reliance on engineered defence measures for floor risk management.

Coastal Flood Risk Management

Present Value damages associated with coastal flooding around Oban are estimated at £10.35 million over the next 100 years. An extensive coastal defence option has been examined and, while capable of significantly reducing coastal flood damages by approximately £4.86 million (over 100 years), the whole life cost of the proposed defences is predicted to exceed these benefits, such that the proposed option is not economically justifiable. A more restricted extent coastal defence option, extending between the Esplanade Court Apartments and the Black Lynn outfall, is predicted to achieve the bulk of the benefit of the extensive option (£4.76 million PV benefit over 100 years) at a lower cost (£3.88 million PV whole life cost), and is therefore more viable. However, costing is based on placement of the proposed defences either upon the existing defensive wall or else between the footpath and A85 road, and costs for this option may be significantly higher if instead land reclamation is needed to site new defences beyond the existing defensive wall.

Noting that average annual damages from coastal flooding are predicted to remain quite low through to 2050, the business case to justify investment in coastal defences in Oban is unlikely to improve significantly in the short term. Therefore, if land reclamation is needed to site new coastal defences, it would be recommended that further consideration of coastal flood defence is deferred, given the reasonable level of protection currently offered by existing defences and natural topography. Instead, emphasis in the short-term should be placed on improving the flood resilience of a small number of properties on or north of North Pier through property level protection.

The following related recommendations are also made in relation to coastal flood risk management:

- Future capital maintenance and development proposals along Corran Esplanade should be mindful of coastal flood risk, and any opportunities to incorporate land raising or de facto defences within proposed works (e.g. road raising, or elevated shoreline footpath sections with parapet walls) should be considered.
- If existing shoreline walls and structures require major capital maintenance repair at some point in the near future, this may present an opportunity to improve the economic justification for progressing a coastal flood defence design, as the cost of the design can be partially offset against capital maintenance costs.

Surface Water Flood Risk Management

Present Value damages due to surface water flooding are estimated very approximately at £3.0 million over the next 100 years. Given the small magnitude of these damages, and the high uncertainty associated with this estimate, it is concluded that there is insufficient need and confidence to recommend any immediate investment to manage surface water flood risk. Instead, a longer-term strategy for minimising the risk of surface water flooding is recommended, to be progressed in collaboration with Scottish Water and other stakeholders, as presented in *Report 2C: Surface Water Management Plan*. However, it remains important to maintain and monitor the performance of the existing surface water pumps in the Lochavullin area, to ensure their effectiveness, and determine if further pumping capacity (here or at other locations) is required to better manage elevated surface water flood risk which can occur when sewer discharge is impeded by high water levels in the Black Lynn.

A OPTION COST SUMMARIES

Conceptual Flood Mitigation Design Costings

A breakdown of costs for each individual conceptual flood mitigation option follows.

These indicative costs are based upon a high-level design. Further detailed design (costed within the 'Whole Project Costs) element will allow further refinement of proposed costs.

The conceptual drawings referenced for the options along with the summary fact sheets for each option are contained in *Report 3C: Conceptual Designs and Factsheets*.

1B Market Street Bridge Replacement

The conceptual design for this proposed flood mitigation is shown in Drawing 170506-069.

Main Elements	**Description**	**Element Cost (inc. 'Optimism Bias'(1))**	**Proportion of option cost**
Channel Works	Including: Bed re-profiling and removal of (approx. $40m^3$) concrete platform on left bank (to east of Kwik Fit).	**£18,279**(2)	1%
Bridge Replacement	Including: demolition and removal of existing arch bridge and abutments, construction of new abutments, up to 60m of retaining walls, new (13m wide, 7m span) flat deck bridge, inclusive of road and footway pavement plus barriers and lighting, specialist traffic management (during road closures and craning) and pollution control measures.	**£1,374,873**(3)	64%
General Project Costs	Including (but not limited to): preliminaries (including general traffic management and insurance), services diversions, site investigation, enabling works (including permits), design and supervision.	**£766,233**(4)	35%
Total		**£2,159,385**	**100%**

(1) Optimism Bias: Calculated costs have been uplifted by 60% (HM Treasury Supplementary Green Book Guidance, 2002) to counter the potential for undue optimism in assessing costs.

(2) Sources of costing: Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019).

(3) Sources of costing: Structures Asset Management Planning Toolkit; Part C: Supporting Information; Version 2.01 (Department for Transport/UK Bridges Board, 2015).

(4) Sources of costing: EnviroCentre Limited's experience of general items costs from managing contractor tender process, design, management of construction and specific construction experience from previous construction management jobs.

2A Lon Mor Attenuation

The conceptual design for this proposed flood mitigation is shown in Drawing 170506-059.

Main Elements	Description	Element Cost (inc. 'Optimism Bias'(1))	Proportion of option cost
Culvert Replacement	Including: Removal of existing bund, replacement of culverts, addition of flow control device and screened headwalls.	**£139,513**(2)	10%
Cyclepath Embankment Replacement	Including: 250m length, 1.8m (average height above ground level), 3.0m crest, 1 in 3 side slopes, and new bituminous pavement.	**£788,288**(3)	55%
General Project Costs	Including (but not limited to): preliminaries (including traffic management and insurance), services diversions, site investigation, enabling works (including permits), design and supervision.	**£510,291**(4)	35%
Total		**£1,438,092**	**100%**

(1) Optimism Bias: Calculated costs have been uplifted by 60% (HM Treasury Supplementary Green Book Guidance, 2002) to counter the potential for undue optimism in assessing costs.

(2) Sources of costing: Cost estimation for culverts – summary of evidence (The Environment Agency, 2014); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019); Supplier Information; EnviroCentre's experience of similar engineering works.

(3) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019); EnviroCentre's experience of similar engineering works.

(4) Sources of costing: EnviroCentre Limited's experience of general items costs from managing contractor tender process, design, management of construction and specific construction experience from previous construction management jobs.

2C Mossfield Stadium Attenuation

The conceptual design for this proposed flood mitigation is shown in Drawing 170506-058.

Main Elements	Description	Element Cost (inc. 'Optimism Bias'(1))	Proportion of project cost
Inflow and Outflow Mechanism	Including; Lower existing bank wall to 13.6mAOD to create inflow mechanism, add inflow spillway, discharge pipe to Alltan Tartach including screened headwalls and flow control (orifice plate); discharge spillway and opposite bank armouring to prevent erosion.	**£103,153**(2)	9%
Barriers to Impound Flood Water	Including; 220m new flood embankment, 40m new flood wall, 146m raised track and 1 pair floodgates.	**£560,418**(3)	50%
Other/Ancillary Works	Including; 150m open drainage ditch, 110m French drain and 110m underground drainage pipe.	**£59,390**(4)	6%
General Project Costs	Including (but not limited to); preliminaries (including traffic management and insurance), services diversions, site investigation, enabling works (including permits), design and supervision.	**£397,628**(5)	35%
Total		**£1,120,589**	**100%**

(1) Optimism Bias: Calculated costs have been uplifted by 60% (HM Treasury Supplementary Green Book Guidance) to counter the potential for undue optimism in assessing costs.

(2) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019).

(3) Sources of costing: Cost estimation for culverts – summary of evidence (The Environment Agency, 2014); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019); Supplier Information; EnviroCentre's experience of similar engineering works.

(4) Sources of costing: Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019); EnviroCentre's experience of similar engineering works.

(5) Sources of costing: EnviroCentre Limited's experience of general items costs from managing contractor tender process, design, management of construction and specific construction experience from previous construction management jobs.

2D Rugby Pitches Attenuation

The conceptual design for this proposed flood mitigation is shown in Drawing 170506-065.

Main Elements	Description	Element Cost (inc. 'Optimism Bias'[(1)])	Proportion of project cost
Inflow and Outflow Mechanism	Including: In-situ cast concrete wall 20m, max 2m height, with cut off, orifice and notch installed within Alltan Tartach; inflow spillway; lower existing access track; discharge pipe including screened headwalls and flow control (orifice plate); exceedance spillway.	**£270,280** [(2)]	22%
Barriers to Impound Flood Water	Including: 450m embankment with 1:3 slope, 1.0m crest up to 1.3m above ground level.	**£440,898**[(3)]	36%
Other/Ancillary Works	Including: 370m French drain east of embankment.	**£92,173**[(4)]	7%
General Project Costs	Including (but not limited to): preliminaries (including traffic management and insurance), services diversions, site investigation, enabling works (including permits), design and supervision.	**£441,843**[(5)]	35%
Total		**£1,245,194**	**100%**

(1) Optimism Bias: Calculated costs have been uplifted by 60% (HM Treasury Supplementary Green Book Guidance) to counter the potential for undue optimism in assessing costs.

(2) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019).

(3) Sources of costing: Cost estimation for culverts – summary of evidence (The Environment Agency, 2014); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019); Supplier Information; EnviroCentre's experience of similar engineering works.

(4) Sources of costing: Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019); EnviroCentre's experience of similar engineering works.

(5) Sources of costing: EnviroCentre Limited's experience of general items costs from managing contractor tender process, design, management of construction and specific construction experience from previous construction management jobs.

3A Black Lynn Flood Defence Walls (up to 3.8mAOD)

The conceptual design for this proposed flood mitigation is shown in Drawing 170506-071.

Main Elements	**Description**	**Element Cost (inc. 'Optimism Bias'(1))**	**Proportion of project cost**
West Bank Flood Protection (Lochavullin Car Park)	Including: 135m Embankment upstream of Soroba Lane Bridge. Average height 1.2m above ground level, side slopes 1:3. Volume 670m^3 (approx.) Includes seepage cut-off to restrict sub-surface flow.	**£421,733**(2)	37%
East Bank Flood Protection (Lidl Car Park)	Including: 120m new flood wall upstream of Soroba Lane Bridge.	**£287,090**(3)	25%
Other/Ancillary Works	Including: Non-return valves to existing and new pipe discharges in the Black Lynn, and soil erosion matting.	**£26,428**(4)	3%
General Project Costs	Including (but not limited to): preliminaries (including traffic management and insurance), services diversions, site investigation, enabling works (including permits), design and supervision.	**£404,388**(5)	35%
Total		**£1,139,639**	**100%**

(1) Optimism Bias: Calculated costs have been uplifted by 60% (HM Treasury Supplementary Green Book Guidance) to counter the potential for undue optimism in assessing costs.

(2) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019); Supplier Information.

(3) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015).

(4) Sources of costing: Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019).

(5) Sources of costing: EnviroCentre Limited's experience of general items costs from managing contractor tender process, design, management of construction and specific construction experience from previous construction management jobs.

3B Black Lynn Flood Defence Walls (up to 4.0mAOD)

The conceptual design for this proposed flood mitigation is shown in Drawing 170506-105.

Main Elements	Description	Element Cost (inc. 'Optimism Bias'[(1)])	Proportion of project cost
West Bank Flood Protection (Lochavullin Car Park)	Including: 140m Embankment upstream of Soroba Lane Bridge. Average height 1.4m above ground level, side slopes 1:3. Volume 925m^3 (approx.) Includes seepage cut-off to restrict sub-surface flow and 15m length of wall raising downstream of Soroba Lane Bridge.	**£480,393**[(2)]	30%
East Bank Flood Protection (Lidl Car Park)	Including: 180m new flood wall upstream of Soroba Lane Bridge, and 15m length of wall raising downstream of Soroba Lane Bridge.	**£462,740**[(3)]	29%
Other/Ancillary Works	Including: Non-return valves to existing and new pipe discharges in the Black Lynn, soil erosion matting, and flood-proofing of the Soroba Lane Bridge.	**£83,773**[(4)]	6%
General Project Costs	Including (but not limited to): preliminaries (including traffic management and insurance), services diversions, site investigation, enabling works (including permits), design and supervision.	**£564,798**[(5)]	35%
Total		**£1,591,704**	**100%**

(1) Optimism Bias: Calculated costs have been uplifted by 60% (HM Treasury Supplementary Green Book Guidance) to counter the potential for undue optimism in asse

(2) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019); Supplier Information.

(3) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019).

(4) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019).

(5) Sources of costing: EnviroCentre Limited's experience of general items costs from managing contractor tender process, design, management of construction and specific construction experience from previous construction management jobs.

3C Millpark Corridor Flood Defences

The conceptual design for this proposed flood mitigation is shown in Drawing 170506-070.

Main Elements	Description	Element Cost (inc. 'Optimism Bias'(1))	Proportion of option cost
Embankment	Including: Woodland/scrub clearance and embankment construction.	**£114,281**(2)	39%
Headwall installation	Including: Woodland/scrub clearance and headwall construction.	**£76,699**(3)	26%
General Project Costs	Including (but not limited to): preliminaries (including traffic management and insurance), services diversions, site investigation, enabling works (including permits), design and supervision.	**£105,039**(4)	35%
Total		**£296,019**	**100%**

(1) Optimism Bias: Calculated costs have been uplifted by 60% (HM Treasury Supplementary Green Book Guidance) to counter the potential for undue optimism in assessing costs.

(2) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019).

(3) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019).

(4) Sources of costing: EnviroCentre Limited's experience of general items costs from managing contractor tender process, design, management of construction and specific construction experience from previous construction management jobs.

4A Miller Road Culvert Dualing

The conceptual design for this proposed flood mitigation is shown in Drawing 170506-068.

Main Elements	Description	Element Cost (inc. 'Optimism Bias'(1))	Proportion of option cost
Installation of new culvert	Including: Construction of 185m long rectangular culvert. 1840m x 800mm.	**£731,120**(2)	55%
Other/Ancillary Works	Including: Inlet & outlet structures, manholes, and over-pumping activities.	**£127,221**(3)	10%
General Project Costs	Including (but not limited to): preliminaries (including traffic management and insurance), services diversions, site investigation, enabling works (including permits), design and supervision.	**£472,088**(4)	35%
Total		**£1,330,429**	**100%**

(1) Optimism Bias: Calculated costs have been uplifted by 60% (HM Treasury Supplementary Green Book Guidance) to counter the potential for undue optimism in assessing costs.

(2) Sources of costing: Cost estimation for culverts – summary of evidence (The Environment Agency, 2014).

(3) Sources of costing: Cost estimation for culverts – summary of evidence (The Environment Agency, 2014); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019).

(4) Sources of costing: EnviroCentre Limited's experience of general items costs from managing contractor tender process, design, management of construction and specific construction experience from previous construction management jobs.

4B Miller Road Floodwater Routing

The conceptual design for this proposed flood mitigation is shown in Drawing 170506-064.

Main Elements	Description	Element Cost (inc. 'Optimism Bias'(1))	Proportion of project cost
Flood routing works	Including: Road raising, pedestrian pavement raising, construction of flood walls, lowering of Miller Road – Soroba Road junction, and property level protection for 3 buildings.	**£321,891**(2)	28%
Flood water re-entry to watercourse	Including: Enhancing Soroba Road inflow at bridge, and upgrading 50m storm sewer.	**£130,129**(3)	12%
Other/Ancillary Works	Including: Disposal of excavated materials.	**£286,153**(4)	25%
General Project Costs	Including (but not limited to): preliminaries (including traffic management and insurance), services diversions, site investigation, enabling works (including permits), design and supervision.	**£405,995**(5)	35%
Total		**£1,144,168**	**100%**

(1) Optimism Bias: Calculated costs have been uplifted by 60% (HM Treasury Supplementary Green Book Guidance) to counter the potential for undue optimism in assessing costs.

(2) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019); Property Protection Advisor (Scottish Flood Forum / JBA Consulting, n.d.).

(3) Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019); EnviroCentre's experience of similar engineering works.

(4) Sources of costing: Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019).

(5) Sources of costing: EnviroCentre Limited's experience of general items costs from managing contractor tender process, design, management of construction and specific construction experience from previous construction management jobs.

6A Extensive Coastal Defence Option

The conceptual design for this proposed flood mitigation is shown in Drawing 170506-055.

Main Elements	Description	Element Cost (inc. 'Optimism Bias'(1))	Proportion of option cost
Oban Esplanade (south of Corran Roundabout)	Including: Construction of 430m new sea wall on beach 2m from existing sea wall, allowing provision for up to 6 access points.	**£3,764,979**(2)	49%
North Pier	Including: Construction of 130m of new sea wall with tie-in to Oban Bay and Esplanade defences, installation of 2 new sets of floodgates to allow retained use of operational area of pier.	**£541,237**(3)	7%
Oban Bay	Including: Removal of crenellations and railings, raising 290m of existing sea wall, allowing provision for up to 3 access points.	**£655,013**(4)	9%
General Project Costs	Including (but not limited to): preliminaries (including traffic management and insurance), services diversions, site investigation, enabling works (including permits), design and supervision.	**£2,728,676**(5)	35%
Total		**£7,689,905**	**100%**

(1) Optimism Bias: Calculated costs have been uplifted by 60% (HM Treasury Supplementary Green Book Guidance) to counter the potential for undue optimism in assessing costs.

(2) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Cost estimation for temporary and demountable defences –summary of evidence (The Environment Agency, 2015).

(3) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Cost estimation for temporary and demountable defences –summary of evidence (The Environment Agency, 2015); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019).

(4) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Cost estimation for temporary and demountable defences –summary of evidence (The Environment Agency, 2015).

(5) Sources of costing: EnviroCentre Limited's experience of general items costs from managing contractor tender process, design, management of construction and specific construction experience from previous construction management jobs.

6B Reduced Extent Coastal Defence Option

The conceptual design for this proposed flood mitigation is shown in Drawing 170506-101.

Main Elements	Description	Element Cost (inc. 'Optimism Bias'(1))	Proportion of option cost
Oban Esplanade (south of Great Western Hotel)	Including: Construction of 235m new sea wall located on existing sea wall, allowing provision for up to 3 access points.	**£971,350**(2)	28%
North Pier	Including: Construction of 130m of new sea wall with tie-in to Oban Bay and Esplanade defences, installation of 2 new sets of floodgates to allow retained use of operational area of pier.	**£541,237**(3)	16%
Oban Bay	Including: Removal of crenellations and railings, raising 290m of existing sea wall, allowing provision for up to 3 access points.	**£655,013**(4)	19%
Other/Ancillary Works	Including: Creation of flood barrier across A85 Oban Esplanade, including road raising and installation of floodgates.	**£66,605**5)	2%
General Project Costs	Including (but not limited to): preliminaries (including traffic management and insurance), services diversions, site investigation, enabling works (including permits), design and supervision.	**£1,228,812**(6)	35%
Total		**£3,463,017**	**100%**

(1) Optimism Bias: Calculated costs have been uplifted by 60% (HM Treasury Supplementary Green Book Guidance) to counter the potential for undue optimism in assessing costs.

(2) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Cost estimation for temporary and demountable defences –summary of evidence (The Environment Agency, 2015).

(3) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Cost estimation for temporary and demountable defences –summary of evidence (The Environment Agency, 2015).

(4) Sources of costing: Cost estimation for fluvial defences –summary of evidence (The Environment Agency, 2015); Cost estimation for temporary and demountable defences –summary of evidence (The Environment Agency, 2015).

(5) Sources of costing: Cost estimation for temporary and demountable defences –summary of evidence (The Environment Agency, 2015); Spon's Civil Engineering and Highway Works Price Book (AECOM/CRC Press, 2019).

(6) Sources of costing: EnviroCentre Limited's experience of general items costs from managing contractor tender process, design, management of construction and specific construction experience from previous construction management jobs.

6C Coastal Property Level Protection

The conceptual design for this proposed flood mitigation is shown in Drawing 170506-126.

Main Elements	Description	Element Cost (inc. 'Optimism Bias'[1])	Proportion of option cost
Flood Barriers	Including: Replacement of existing doors with automatic inflatable sealing flood door and low-lying window protection	**£179,200**[2]	48%
Dewatering	Including: Installation of pump with (either internal or external) sump & provision of portable skimmer pump.	**£98,560** [3]	26%
Other/Ancillary Works	Including: Replacement of airbricks with automatic airbricks/air vent protection, installation of full port non-return valve for use in foul chamber/manhole (to be added), addition of appliance non-return valves; repointing external walls with water resistant mortar, sealing around openings for cables etc. and waterproofing external walls.	**£79,200** [4]	21%
General Project Costs	Including property surveys and insurance	**£17,848** [5]	5%
Total		**£374,808**	**100%**

(1) Optimism Bias: Calculated costs have been uplifted by 60% (HM Treasury Supplementary Green Book Guidance) to counter the potential for undue optimism in assessing costs.

(2) Sources of costing: Scottish Flood Forum; Supplier Information;

(3) Sources of costing: Scottish Flood Forum; Supplier Information;

(4) Sources of costing: Scottish Flood Forum; Supplier Information;

(5) Sources of costing: EnviroCentre Limited's experience of general items costs from previous construction management jobs.

B BASELINE FLUVIAL-TIDAL FLOOD MAPS

Do not scale this map

Legend

Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	Baseline 1 in 2 Year RP Fluvial Flood Depth 9 Hour Critical Flood Event Current Day
Status	FINAL
Drawing No.	170506-127
Revision	A
Scale	1:7,500
	A3
Date	13 Dec 2019
Drawn	JP
Checked	MN
Approved	MN

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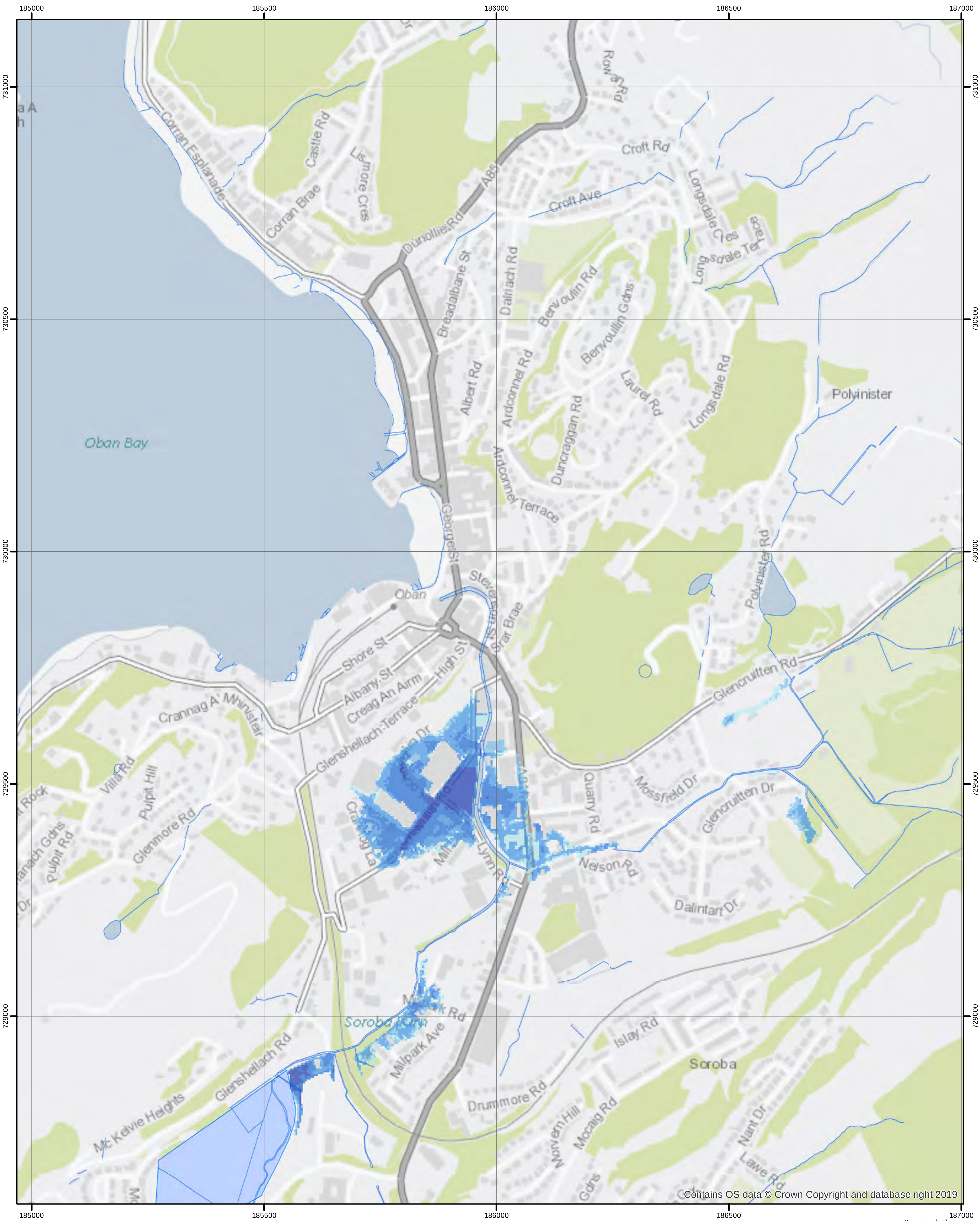

Do not scale this map

Legend

Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	Baseline 1 in 50 Year RP Fluvial Flood Depth 9 Hour Critical Flood Event Current Day
Status	FINAL
Drawing No.	170506-128
Revision	A
Scale	1:7,500
Size	A3
Date	13 Dec 2019
Drawn	JP
Checked	MN
Approved	MN

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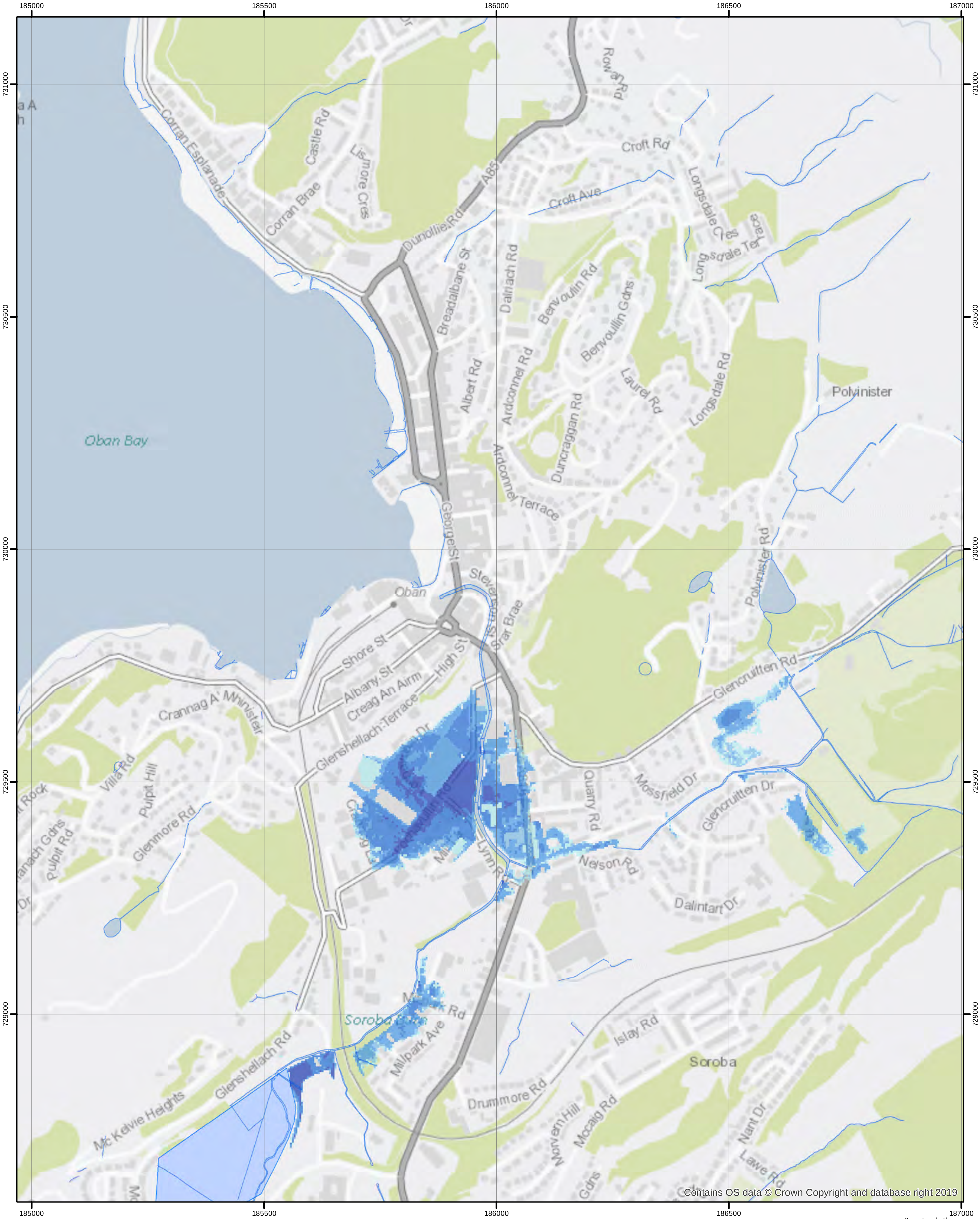

Do not scale this map

Legend

Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	Baseline 1 in 200 Year RP Fluvial Flood Depth 9 Hour Critical Flood Event Current Day
Status	FINAL
Drawing No.	170506-129
Revision	A
Scale	1:7,500
Size	A3
Date	13 Dec 2019
Drawn	JP
Checked	MN
Approved	MN

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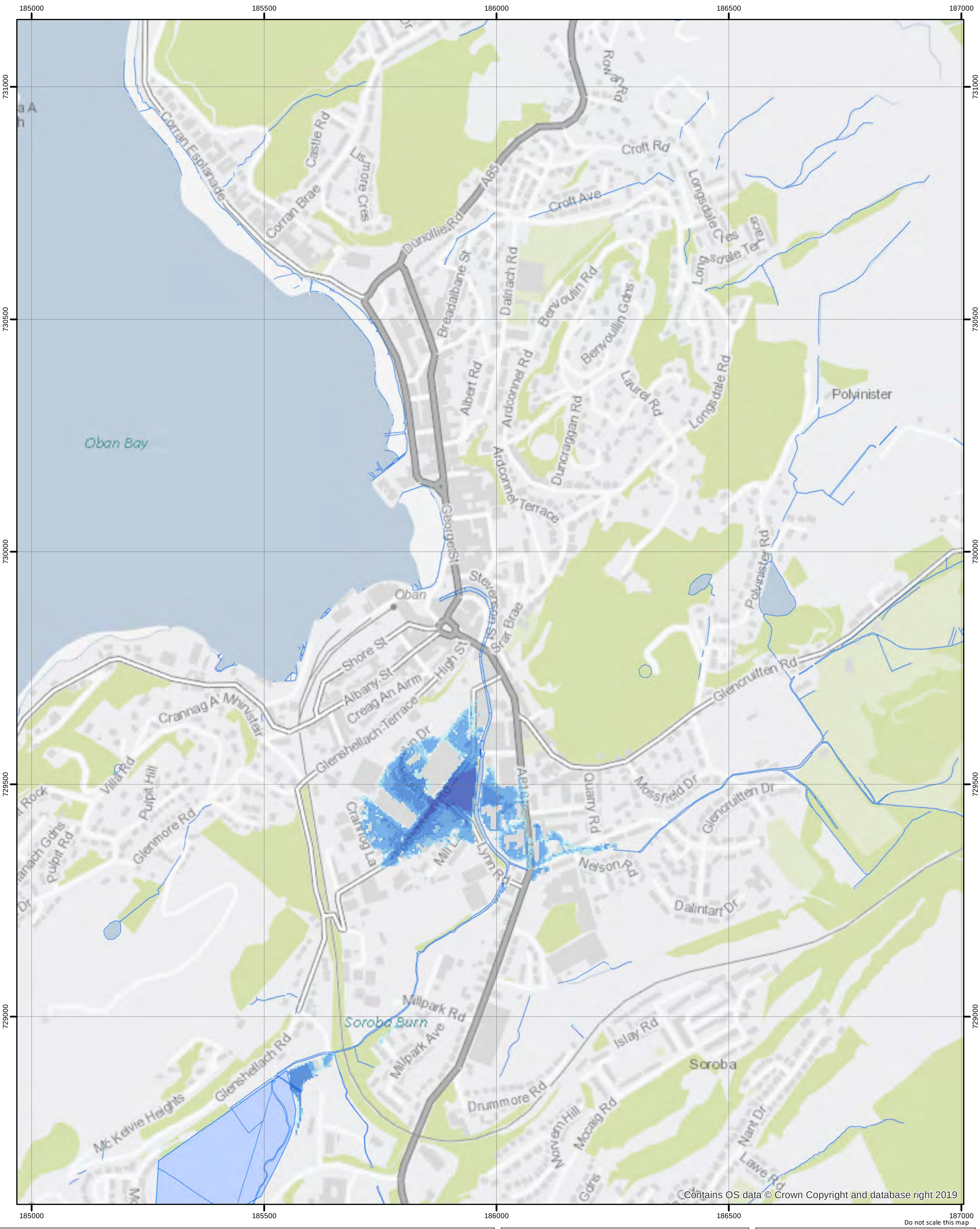

Legend

Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	Baseline 1 in 2 Year RP Fluvial Flood Depth 9 Hour Critical Flood Event Future Climate (2100)
Status	FINAL
Drawing No.	170506-130
Revision	A
Scale	1:7,500
Size	A3
Date	13 Dec 2019
Drawn	JP
Checked	MN
Approved	MN

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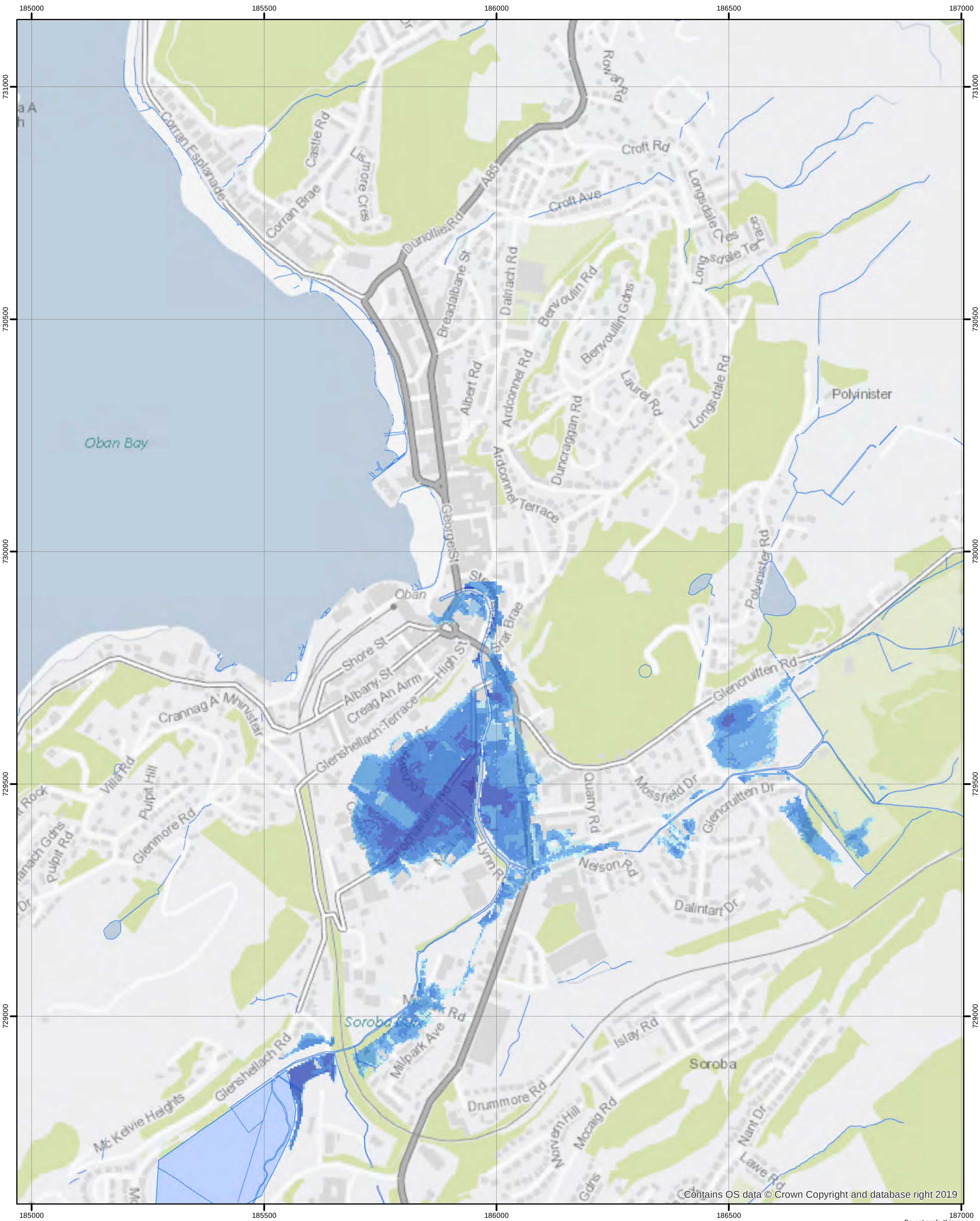

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Legend

Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	Baseline 1 in 50 Year RP Fluvial Flood Depth 9 Hour Critical Flood Event Future Climate (2100)
Status	FINAL
Drawing No.	170506-131
Revision	A
Scale	1:7,500
Size	A3
Date	13 Dec 2019
Drawn	JP
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Approved	MN

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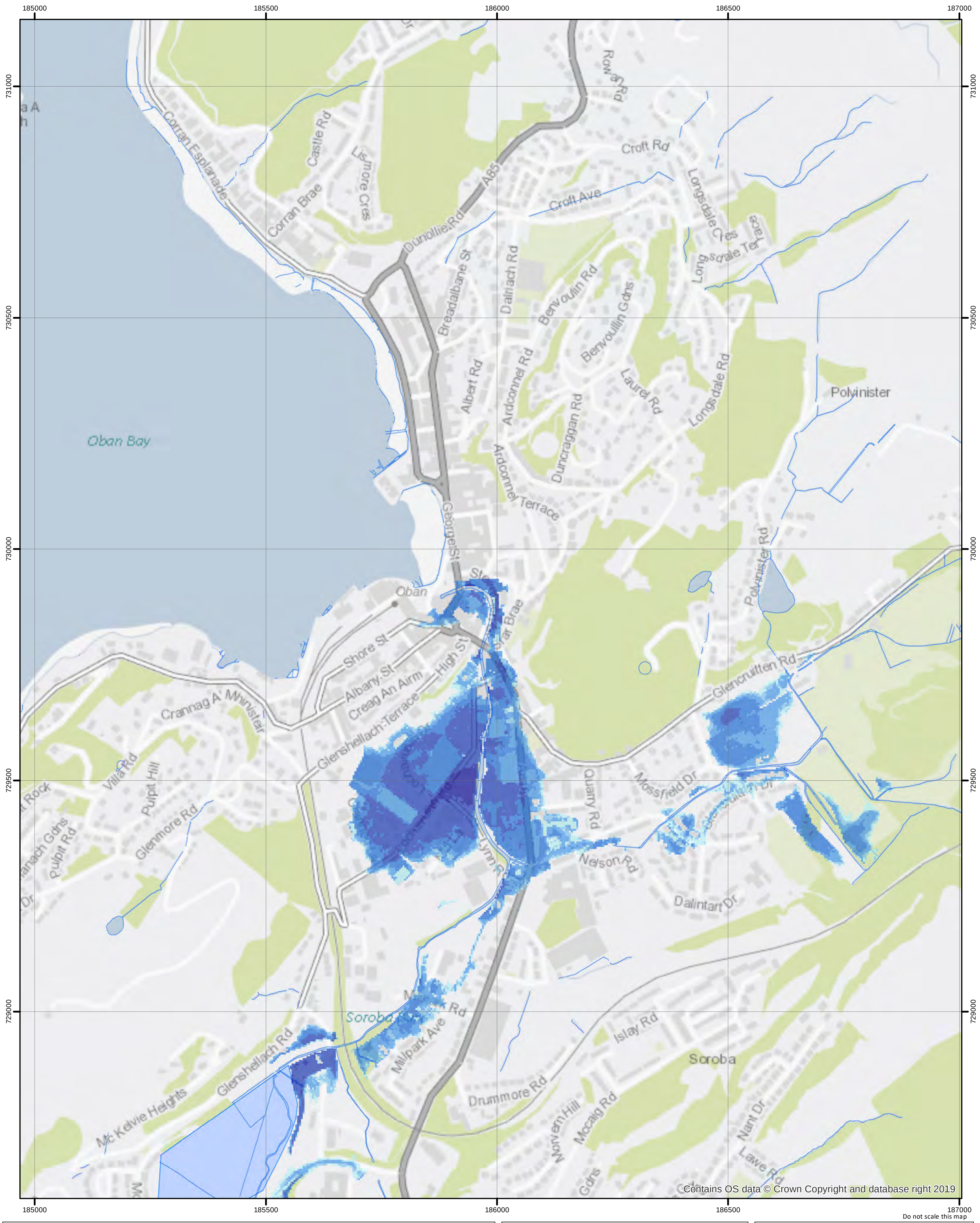

Legend

- Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	Baseline 1 in 200 Year RP Fluvial Flood Depth 9 Hour Critical Flood Event Future Climate (2100)
Status	FINAL
Drawing No.	170506-132
Revision	A
Scale	1:7,500
Size	A3
Date	13 Dec 2019
Drawn	JP
Checked	MN
Approved	MN

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C PREFERRED OPTION FLUVIAL-TIDAL FLOOD MAPS

Do not scale this map

Legend

Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	Option 1 in 2 Year RP Fluvial Flood Depth 9 Hour Critical Flood Event Current Day
Status	FINAL
Drawing No.	170506-133
Revision	A
Scale	1:7,500
Size	A3
Date	13 Dec 2019
Drawn	JP
Checked	MN
Approved	MN

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Do not scale this map

Legend

Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	Option 1 in 50 Year RP Fluvial Flood Depth 9 Hour Critical Flood Event Current Day

Status	FINAL	
Drawing No.	170506-134	Revision: A
Scale: 1:7,500	A3	Date: 13 Dec 2019
Drawn: JP	Checked: MN	Approved: MN

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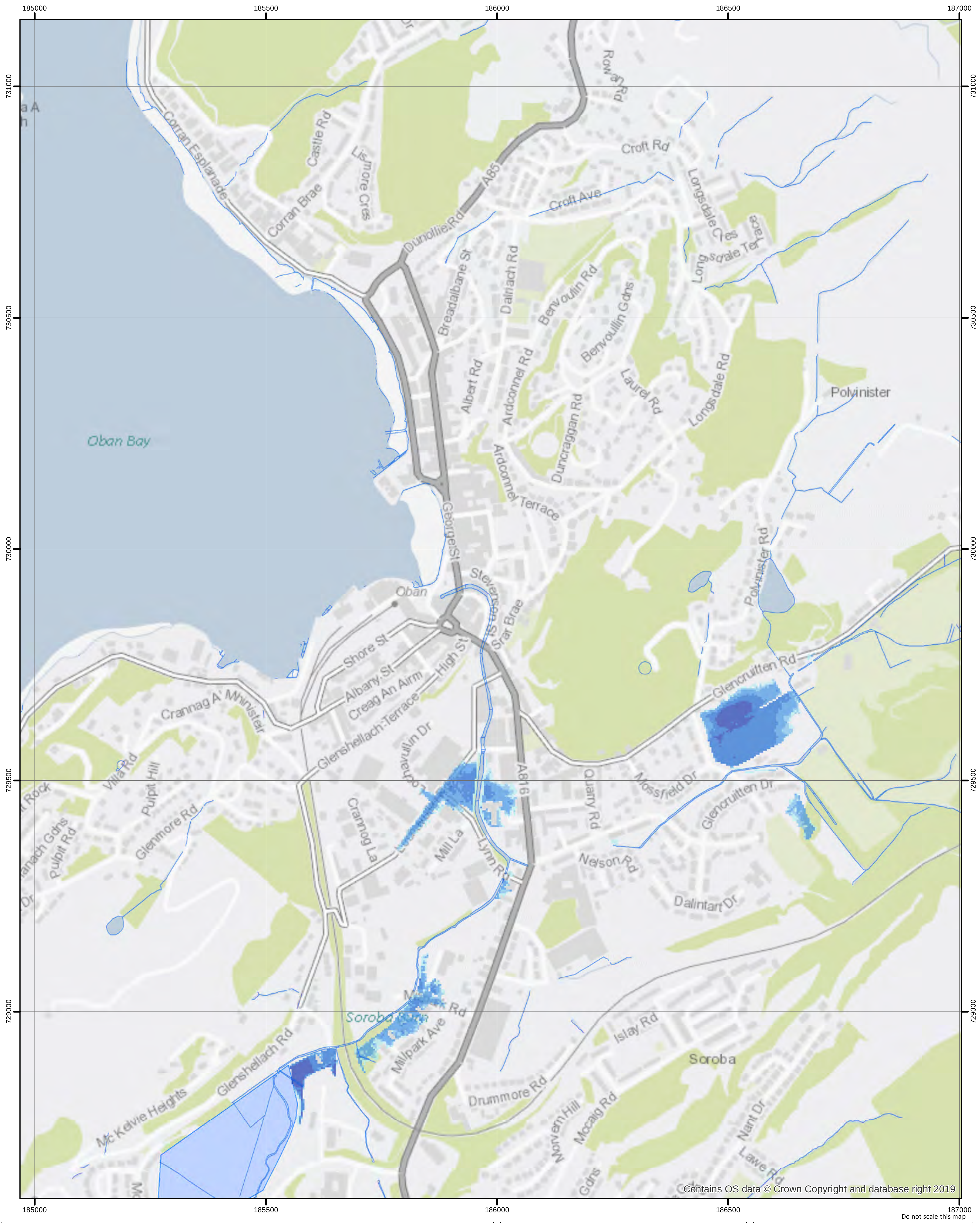

Legend

- Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	Option 1 in 200 Year RP Fluvial Flood Depth 9 Hour Critical Flood Event Current Day
Status	FINAL
Drawing No.	170506-135
Revision	A
Scale	1:7,500
Size	A3
Date	13 Dec 2019
Drawn	JP
Checked	MN
Approved	MN

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Legend

Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	Option 1 in 2 Year RP Fluvial Flood Depth 9 Hour Critical Flood Event Future Climate (2100)
Status	FINAL
Drawing No.	170506-136
Revision	A
Scale	1:7,500
Size	A3
Date	13 Dec 2019
Drawn	JP
Checked	MN
Approved	MN

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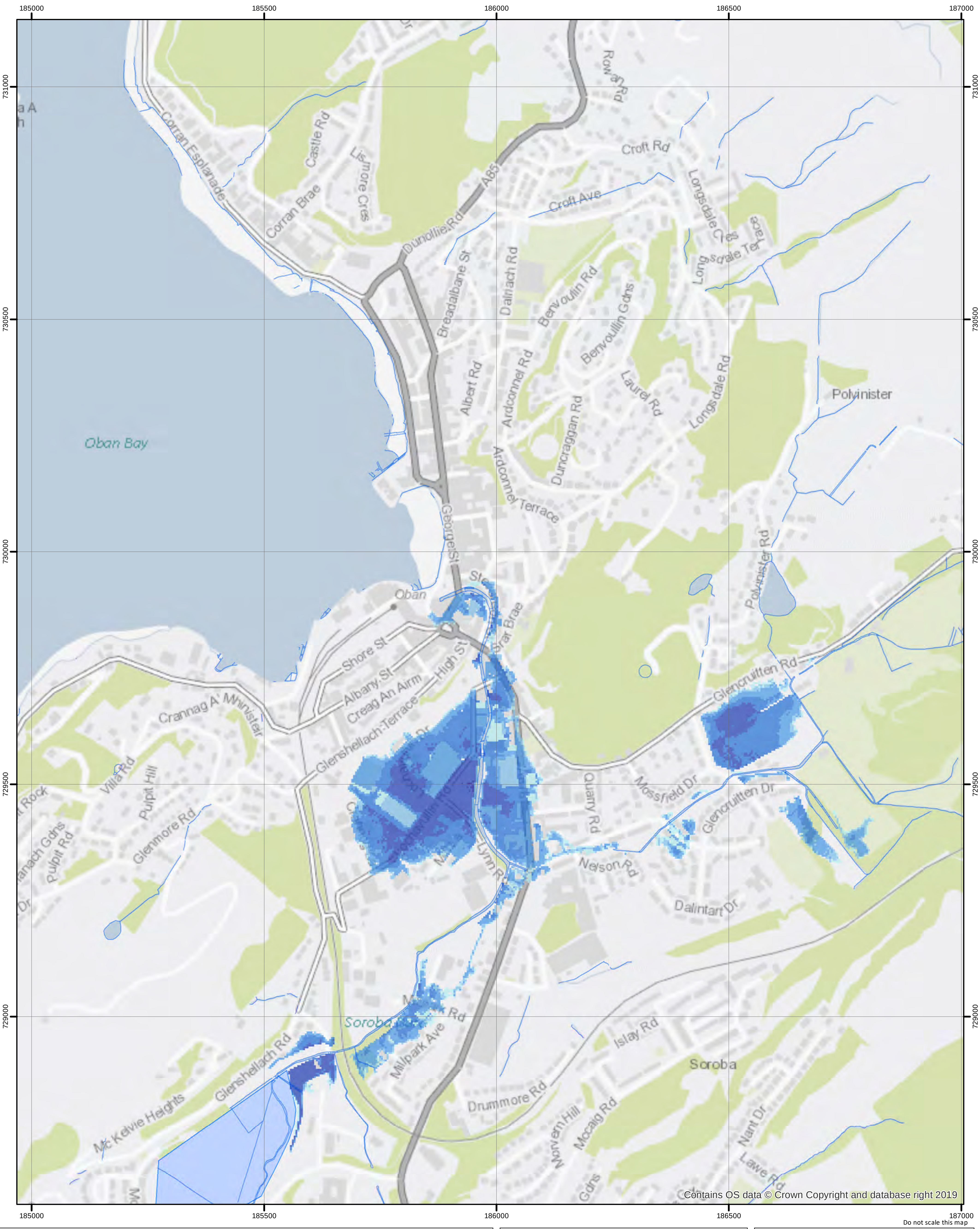

Legend

Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client: Argyll and Bute Council

Project: Oban Flood Study

Title: Option 1 in 50 Year RP Fluvial Flood Depth
9 Hour Critical Flood Event
Future Climate (2100)

Status	FINAL
Drawing No.	170506-137
Revision	A
Scale	1:7,500
Size	A3
Date	13 Dec 2019
Drawn	JP
Checked	MN
Approved	MN

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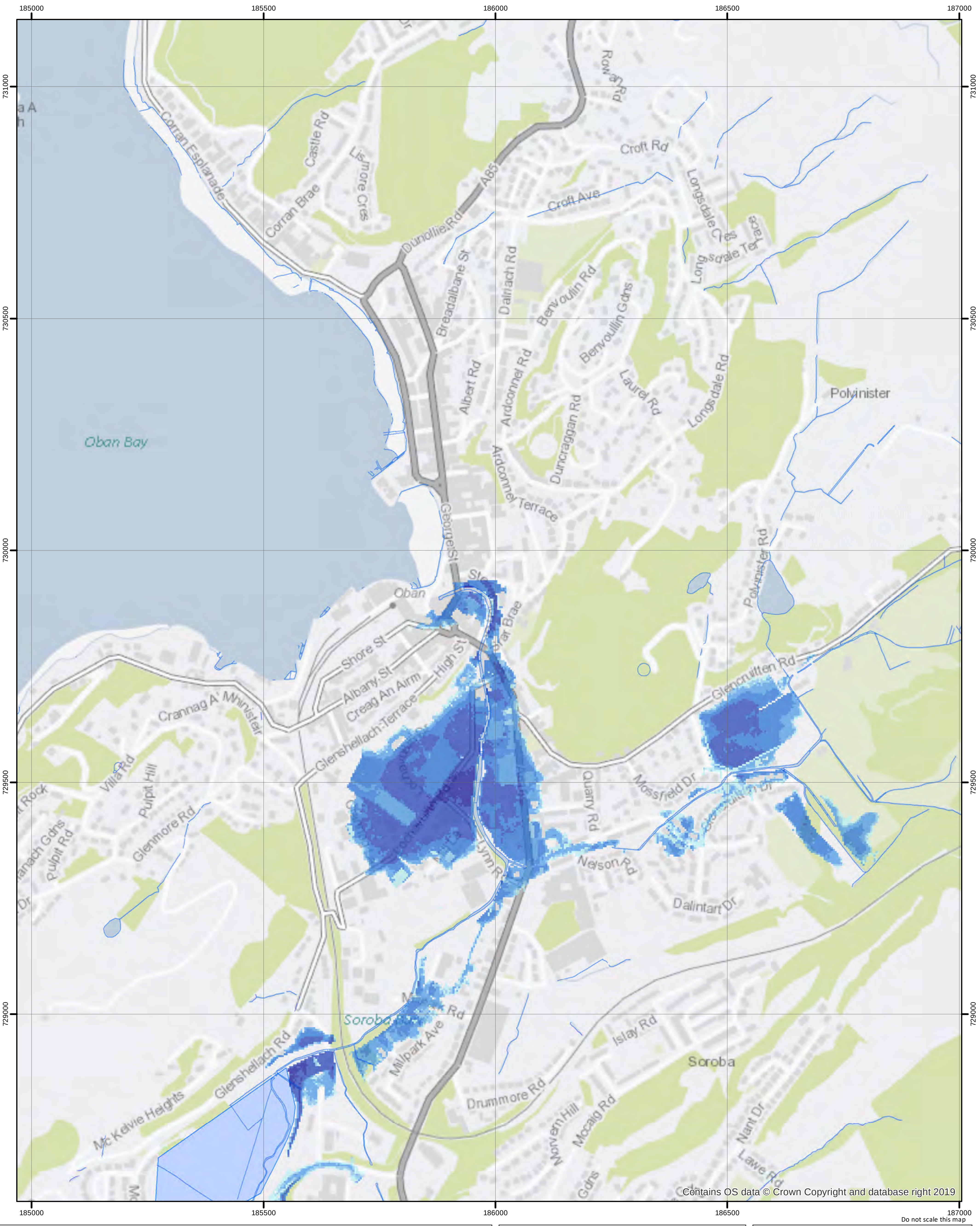

Legend

Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	Option 1 in 200 Year RP Fluvial Flood Depth 9 Hour Critical Flood Event Future Climate (2100)
Status	FINAL
Drawing No.	170506-138
Revision	A
Scale	1:7,500
Size	A3
Date	13 Dec 2019
Drawn	JP
Checked	MN
Approved	MN

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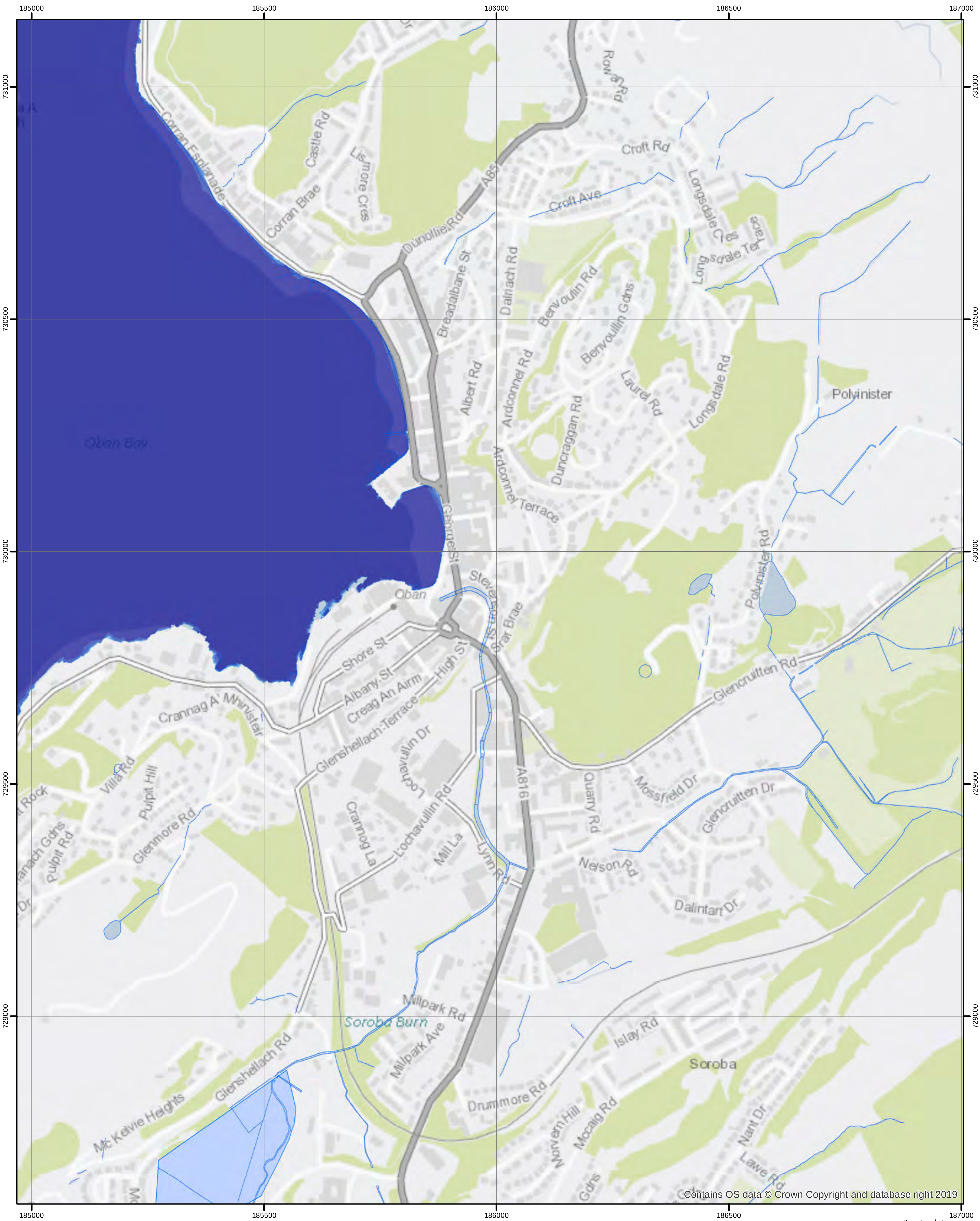
D BASELINE COASTAL FLOOD MAPS



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Legend

Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	1 in 2 Year RP Coastal Flood Depth Includes Waves Current Day
Status	FINAL
Drawing No.	170506-139
Revision	A
Scale	1:7,500
Size	A3
Date	13 Dec 2019
Drawn	JP
Checked	MN
Approved	MN

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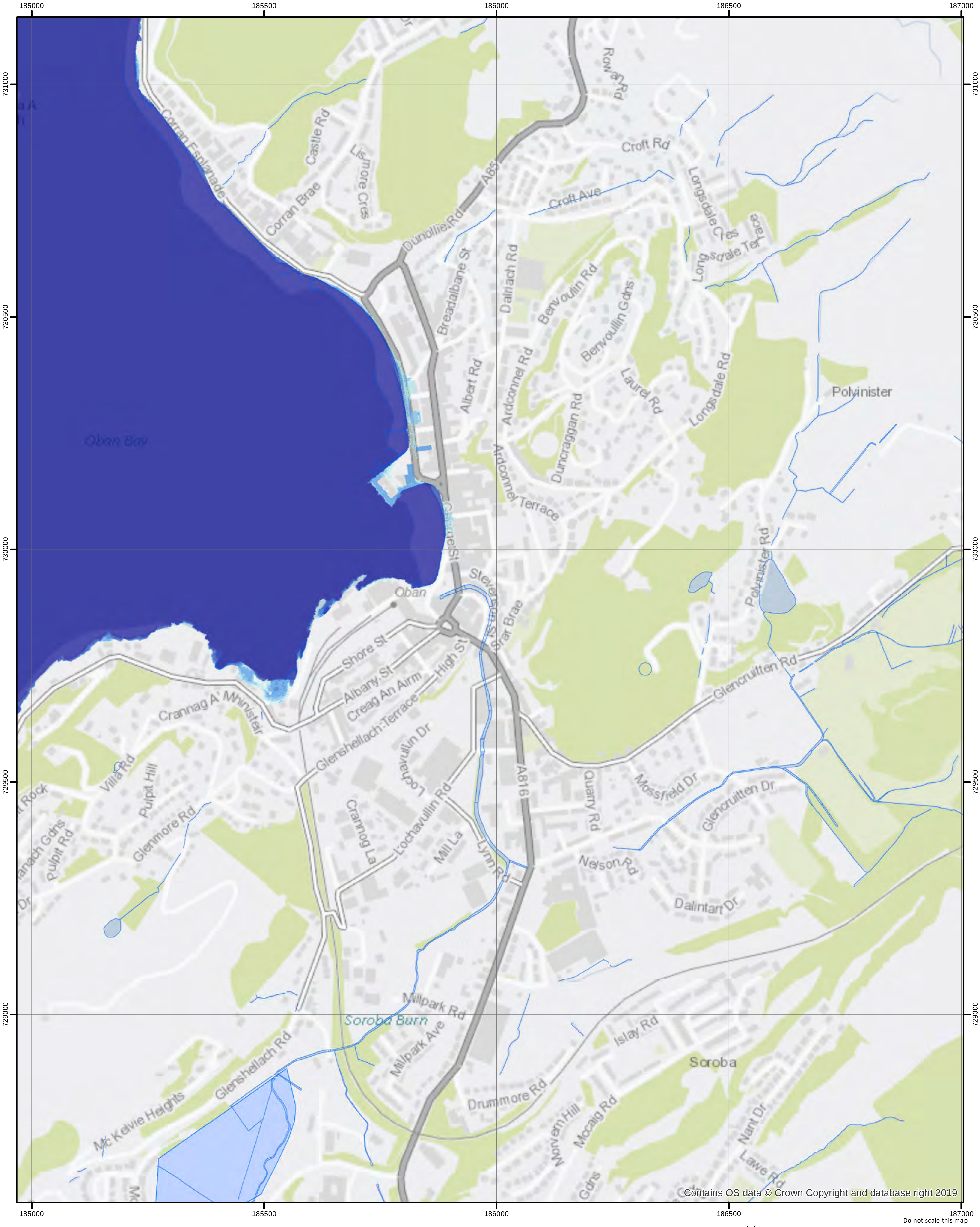

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Legend

Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	1 in 50 Year RP Coastal Flood Depth Includes Waves Current Day

Status	FINAL	
Drawing No.	170506-140	Revision: A
Scale	1:7,500	A3
Date	13 Dec 2019	
Drawn	Checked	Approved
JP	MN	MN

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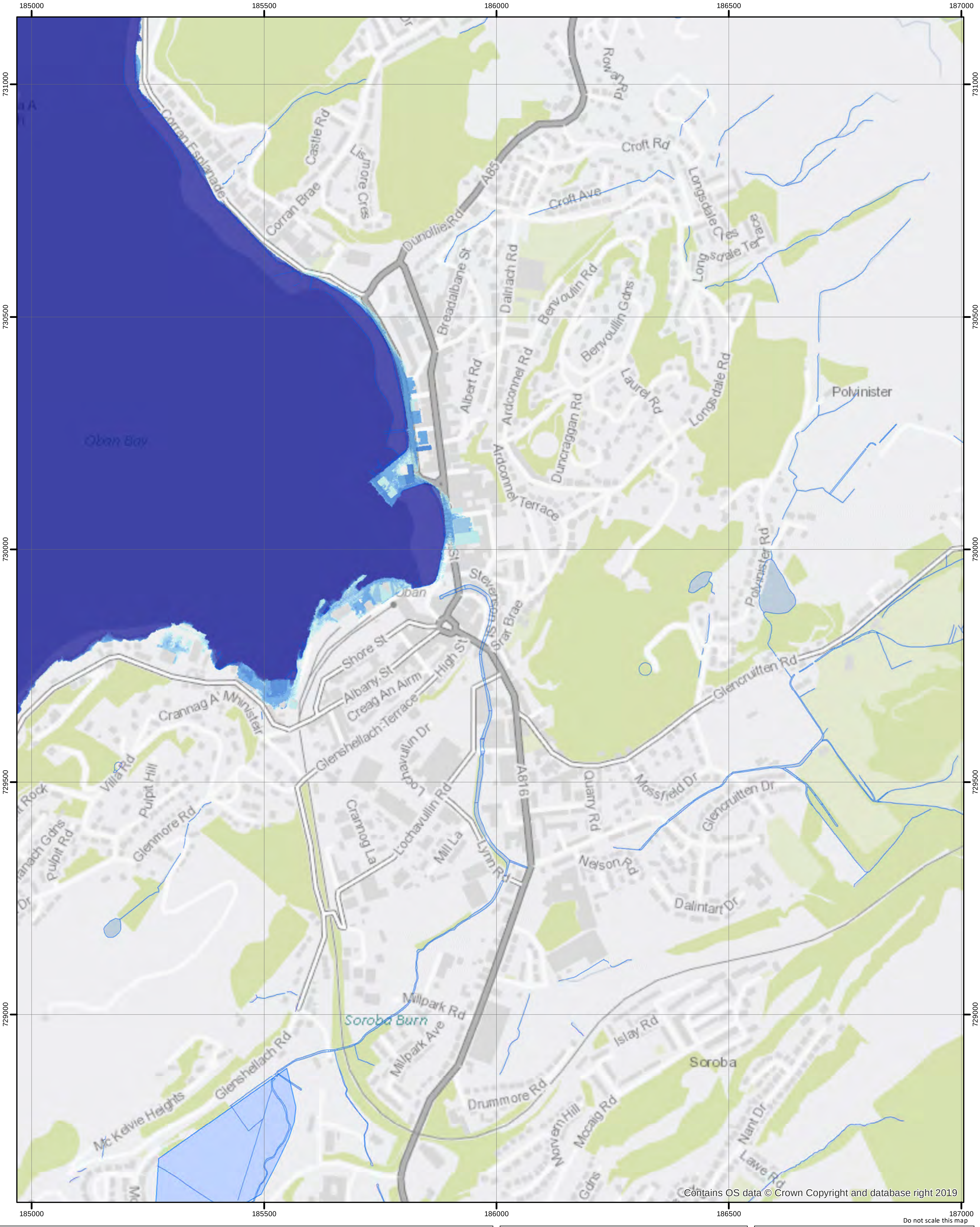


Do not scale this map

Legend

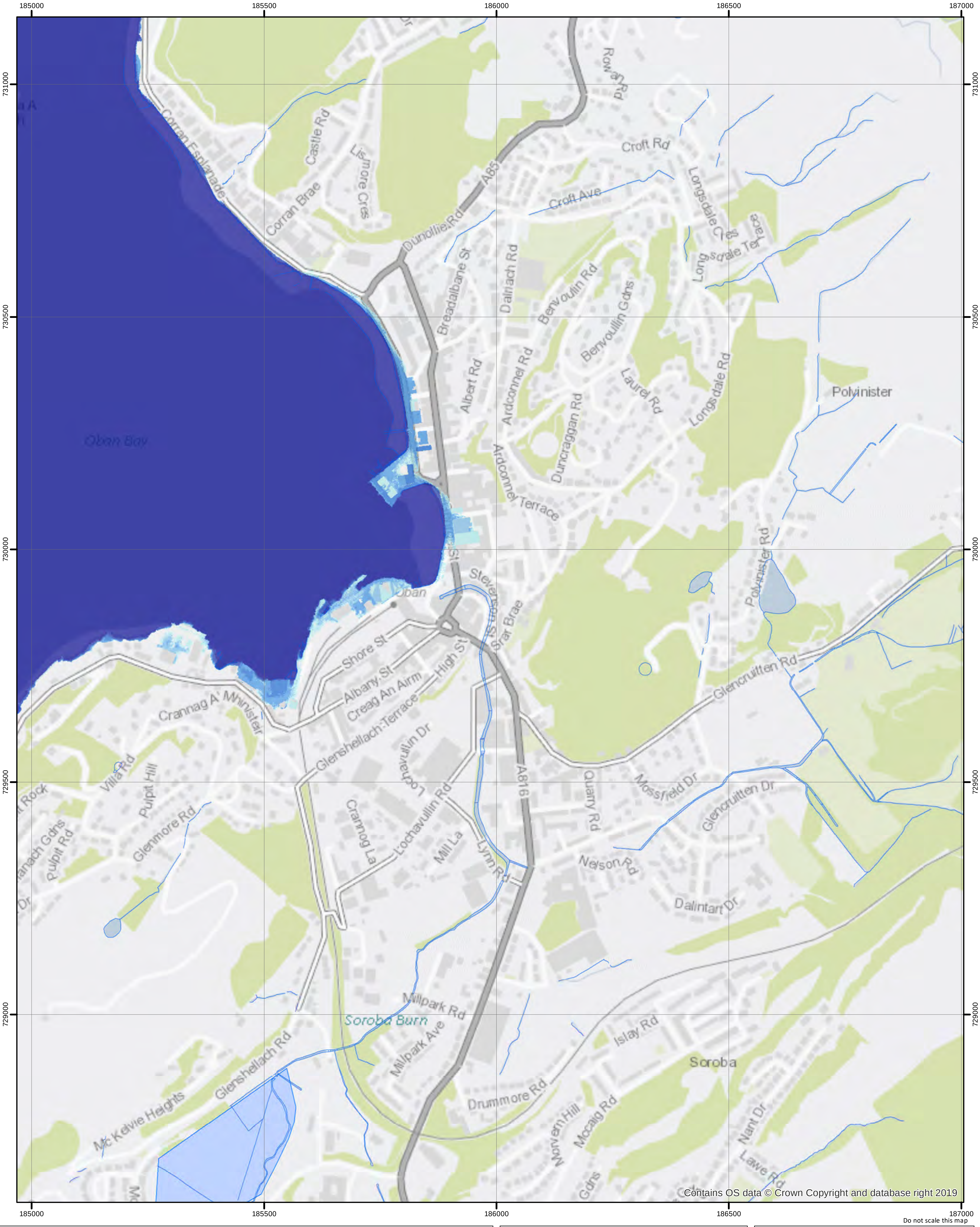
Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	1 in 200 Year RP Coastal Flood Depth Includes Waves Current Day
Status	FINAL
Drawing No.	170506-141
Revision	A
Scale	1:7,500
Size	A3
Date	13 Dec 2019
Drawn	JP
Checked	MN
Approved	MN

Craighall Business Park, Eagle Street, Glasgow, G4 9XA
Tel: 0141 341 5040
Fax: 0141 341 5045



Do not scale this map

Legend

Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

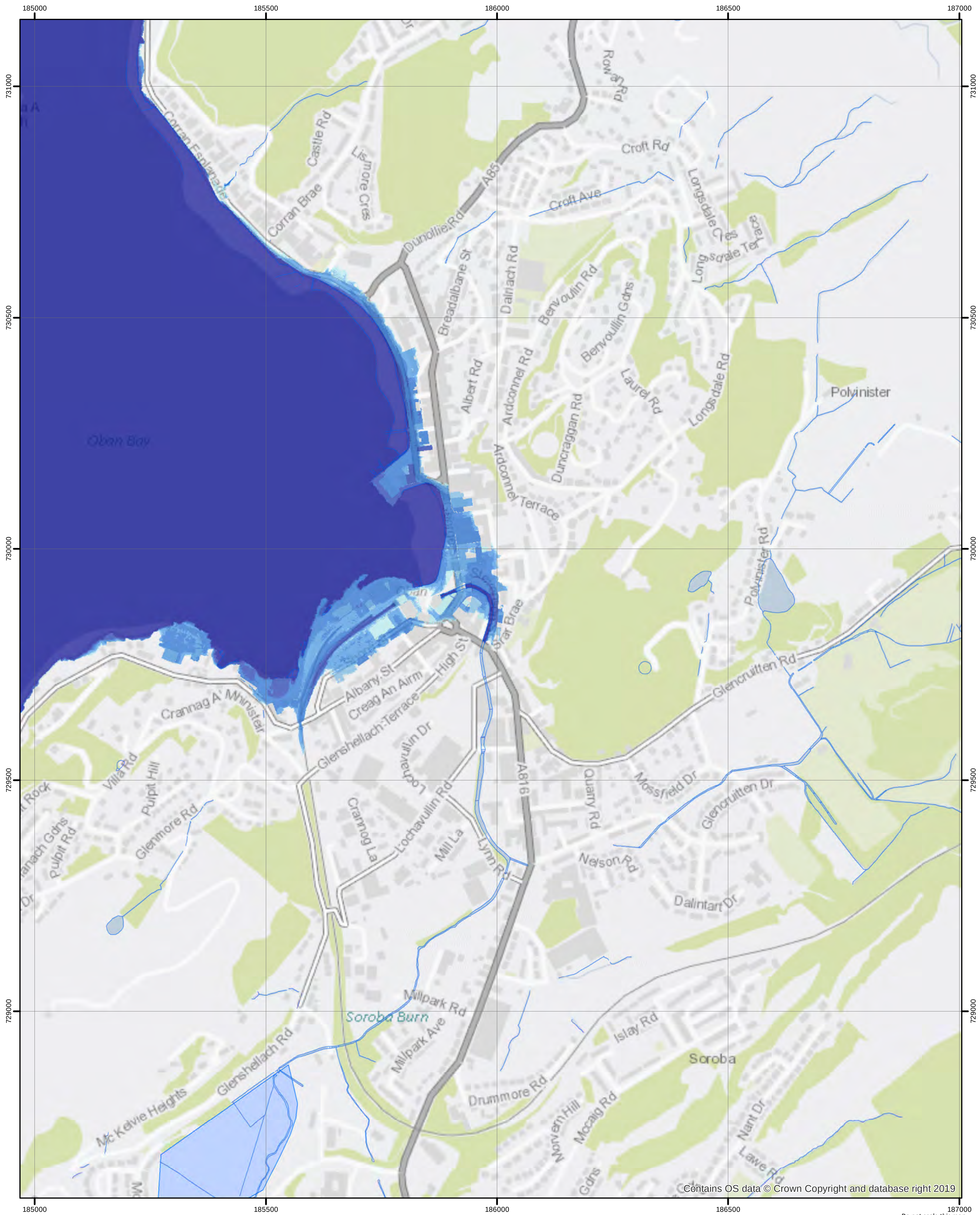
Client
Argyll and Bute Council

Project
Oban Flood Study

Title
1 in 2 Year RP Coastal Flood Depth
Includes Waves
Future Climate (2100)

Status		
FINAL		
Drawing No. 170506-142		Revision A
Scale 1:7,500	A3	Date 13 Dec 2019
Drawn JP	Checked MN	Approved MN

ENVIRO Centre
Craighall Business Park, Eagle Street, Glasgow, G4 9XA
Tel: 0141 341 5040
Fax: 0141 341 5045



Do not scale this map

Legend

- Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client: Argyll and Bute Council

Project: Oban Flood Study

Title: 1 in 50 Year RP Coastal Flood Depth Includes Waves Future Climate (2100)

Status	FINAL		
Drawing No.	170506-143	Revision	A
Scale	1:7,500	A3	Date: 13 Dec 2019
Drawn: JP	Checked: MN	Approved: MN	

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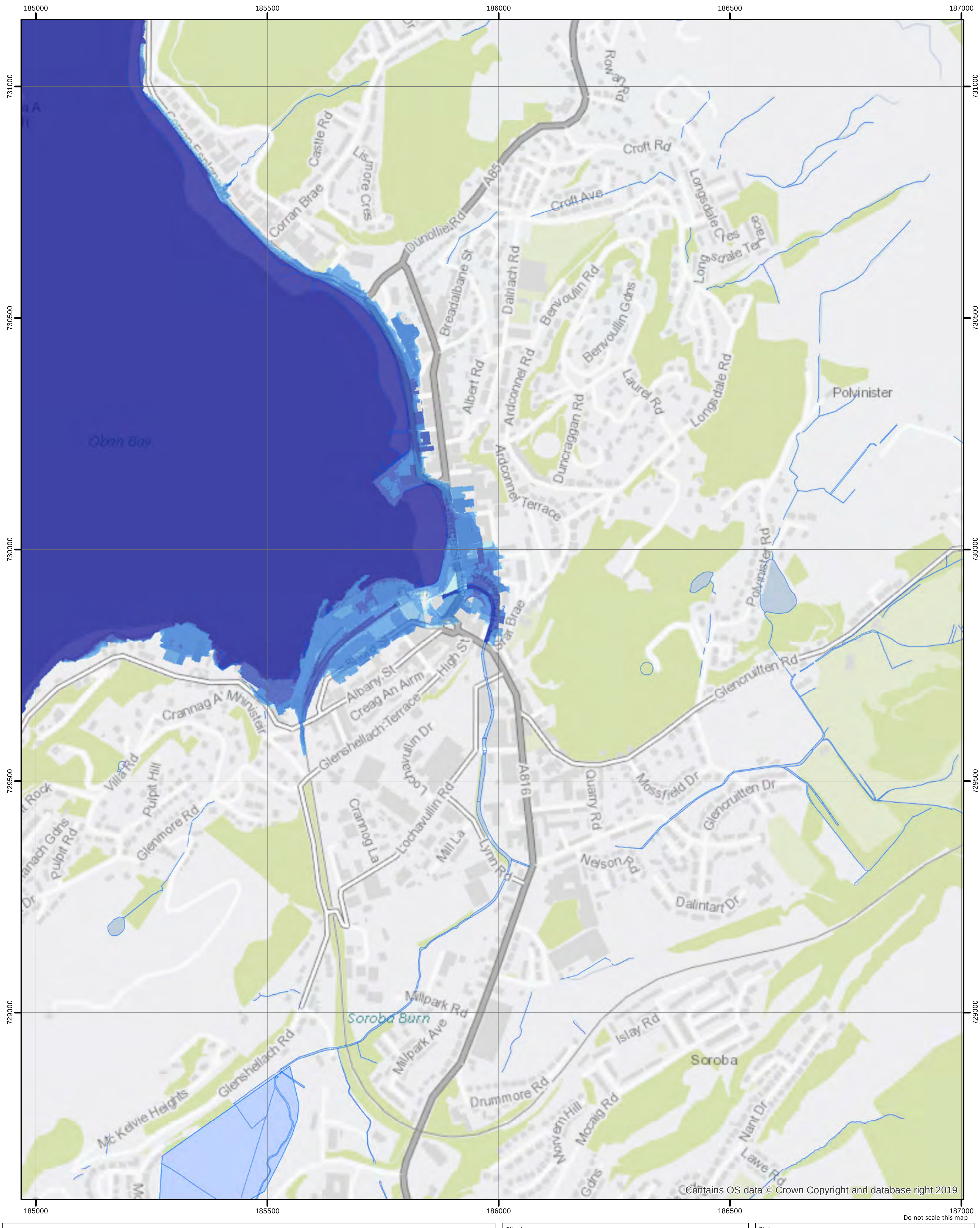
Tel: 0141 341 5040
Fax: 0141 341 5045



Legend

- Watercourses

Flood Depth (m)

- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- > 2.0

Client	Argyll and Bute Council
Project	Oban Flood Study
Title	1 in 200 Year RP Coastal Flood Depth Includes Waves Future Climate (2100)
Status	FINAL
Drawing No.	170506-144
Revision	A
Scale	1:7,500
Size	A3
Date	13 Dec 2019
Drawn	JP
Checked	MN
Approved	MN

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